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FACULTY OF HUMANITIES
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A STUDY OF LIFE SCIENCES PROJECTS IN SCIENCE TALENT QUEST COMPETITIONS IN THE WESTERN CAPE, SOUTH AFRICA, WITH SPECIAL REFERENCE TO SCIENTIFIC SKILLS AND KNOWLEDGE

A dissertation submitted for the degree of

DOCTOR OF PHILOSOPHY

By

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DECLARATION

I declare that *A study of Life Sciences projects in science talent quest competitions in the Western Cape, South Africa, with special reference to scientific skills and knowledge* is my own original and unaided work, except where indicated, and that it has not been submitted before for any degree or examination at any University.

Signed:

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20–09–2011

ABSTRACT

In 2003, the South African Department of Education released its National Curriculum Statement for Schools, Grades 10–12 (General), for Life Sciences. The curriculum emphasises that scientific skills are best developed within the context of an expanding framework of knowledge. ESKOM Expos for Young Scientists (i.e., science talent quest competitions) provide such a context.

The present study focuses on educational outcomes of selected 2007 Expo participants, namely, scientific skills (that is, process skills, scientific inquiry, problem solving and critical thinking skills) and Life Sciences knowledge, as well as on the opportunities the Expos provided for the students to develop such educational outcomes.

In an effort to learn whether the Expos allow students to develop scientific skills and Life Sciences knowledge in line with the recommendations of the National Curriculum Statement for Life Sciences, the following were the research questions of the study, which I sought to answer within the context of Expos in the Western Cape:

- What factors shaped school students' participation in the ESKOM Expo competitions for Young Scientists?
- How did the students' Expo projects facilitate the development of scientific skills and Life Sciences knowledge?
- What articulation occurred between the Expos, the science curriculum and science classroom practices in support of the students' development of scientific skills and Life Sciences knowledge?

A multiple case study research design was used to answer the research questions. The cases were purposefully selected from a pool of Expo students who showcased their projects at the two main exhibition venues in the Western Cape, South Africa. The cases comprised five Grades 10–11 students from three schools.

Four sets of data were used to answer the research questions, namely semi–structured interviews with Expo students and their mentors, a semi–structured questionnaire administered to the Expo students, and the students' project reports themselves.

By combining the interviews and document analysis (i.e., using the questionnaire and

the project reports), it was possible to explore whether Expos enable students to develop the desired educational outcomes, and if so, how. The multiple data collection strategies formed the basis for triangulation of data.

In relation to the factors that shaped the students' participation in the Expos, the results showed that the concept of personal relevance, interest, and curiosity play a significant role in Expo students learning. Furthermore, Expo students learning reflected the role played by their families and home life. Such learning also revealed the importance of collaborative interactions with peers and teachers at school, and the benefits of effective science teaching in tandem with extra–curricular science activities. The results, therefore, highlight the importance of making what students learn in Life Sciences relevant to their lives. Drawing on Millar and Driver (1987), this can be achieved by supplying contexts which are charged with relevance to students' interests and concerns, and which can offer sufficient support at home and strategies and frameworks at school which are essential for deepening their understanding of processes, concepts and purposes of science.

In relation to the students' scientific skills and Life sciences knowledge, the results showed Expo students' proficiency in critical inquiry, reflection, the understanding of Life Sciences concepts and processes and their application in society. However, the triangulation technique used elicited nuances of evidence of the students' shortcomings in relation to their performance regarding certain science process skills. The results showed the students' misconceptions related to certain process skills. The students' shortcomings were also reflected in evidence from different sources of data regarding their development of Life Sciences knowledge. The students had a limited understanding of the scientific method in relation to science process skills they believed they had developed. Moreover, the Expo students were challenged when asked to account for how they interpreted information, and to provide descriptions and explanations of biological phenomena under investigation. However, evidence in their Expo reports showed that they were able to use relevant information, the data collected, and the resources they had to interpret and make sense of the information and data. The results thus highlight an association between Expo students' understanding of scientific skills and their performance regarding the skills, as well as their ability to communicate the new Life Sciences knowledge they had developed. Such an association was more evident in Expo students' responses during interviews regarding interpreting information. Their incorrect responses were particularly rooted in their lack of understanding of what basic sub–skills are *integrated* in interpreting information.

In relation to a possible tension or a successful interplay between the Expos, the science classroom practices, and/or the South African science curriculum, the results showed that there is articulation between the intentions of Expos and those of the National Curriculum Statement (NCS) policy in relation to students learning Life Sciences. Expos were avenues of students' exploration of educational and potential career opportunities at tertiary level such as, for example, studying medicine. This mirrors the intention of the NCS policy, where the Developmental Outcomes of the Life Sciences curriculum emphasise students' exploration of education and career opportunities.

Scientific investigations under the umbrella of Expos have a considerable potential to develop students' scientific skills and Life Sciences knowledge. They are a cornerstone in the interplay between the curriculum and the Expos. As a result, they are recommended as part of enrichments in the South African schools' science curricula. However, schools should anticipate challenges related to pedagogical issues. Such challenges may include, for instance, considerable time used in developing students' basic skills and/or helping the students to make sense of their data. Resources and facilities are also essential for highly successful projects. Moreover, it is important that schools are knowledgeable of their students' characteristics (e.g., students with good writing skills can handle projects that require extensive use of written material) and have clear intentions in relation to students learning within a context of an expanding framework of knowledge (e.g., use research projects with students that, for instance, are self–motivated and are able to learn with minimal assistance).

Key words: Critical thinking, ESKOM Expos for Young Scientists, Grades 10-12, Life Sciences, Life Sciences concepts, National Curriculum Statement, science process skills, scientific inquiry, science talent quest competitions, South Africa, Western Cape

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LIST OF ABBREVIATIONS

APU	Assessment Production Unit
C2005	Curriculum 2005
CV	Curriculum Vitae
DoE	Department of Education
DBP	Diastolic blood pressure
Expo	ESKOM Expo for Young Scientists
FET	Further Education and Training phase
HRT	Hormone Replacement Therapy
IT	Information Technology
LO	Learning Outcome
NCS	National Curriculum Statement
OBE	Outcomes-Based Education
PR	Pulse rate
SAMA	South African Medical Association
SBP	Systolic blood pressure
TIMSS	Third International Mathematics and Science Study
TV	Television
UCT	University of Cape Town
WCDE	Western Cape Department of Education
WHIS	Women’s Health Initiative Study

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PART 2: THE ROLE OF SCIENCE PROCESS SKILLS IN SCIENCE LEARNING

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CHAPTER 1

INTRODUCTION

Introduction to the study

This research study examined meritorious Grades 10–11 Expo students who participated in the 2007 ESKOM Expos for Young Scientists (science talent quest competitions) held in the Western Cape, South Africa. It investigated the development of their scientific skills, that is, process skills, particular scientific inquiry, problem solving and critical thinking skills, as well as their Life Sciences knowledge. Furthermore, as this was an in–depth study that attempted to develop an understanding of how students learn through investigation projects in Expos, it was important to further investigate pertinent experiences of the students which might have influenced development of their skills and knowledge.

Background and rationale

Curriculum reforms in post–apartheid South Africa occurred after the 1994 elections (Department of Education: DoE, 2002). The reforms became a master plan meant to "purge apartheid curriculum (school syllabuses) of 'racially offensive and outdated content'" (Jansen, 1998, p. 321). In 1994, South Africa thus saw a significant breakthrough towards a non–racial and democratic society (Harley & Wedekind, 2004). The country's challenge was to restructure the apartheid curriculum in order to rectify the educational imbalances of the apartheid regime and to provide equal educational opportunities for all South Africans (DoE, 2003b). This led to the first National Curriculum Statement – *Curriculum 2005* (C2005) (Harley & Wedekind, 2004). Harley and Wedekind (2004) and Pudi (2006) stated that the unfolding educational transformation in South Africa saw *C2005* being subsequently replaced by the National Curriculum Statement[1] (NCS). The progression to NCS was rooted in the need to fill gaps that were discovered when *C2005* was subjected to a review (Pudi, 2006). NCS is thus the result of the revised, strengthened and streamlined *C2005*.

[1] The National Curriculum Statement is also referred to as Revised National Curriculum Statement at the General Education and Training phase (Grades R–9)

The NCS represents a policy statement for learning and teaching in schools at the Further Education and Training phase (FET) (DoE, 2003a). FET is responsible for the development of educational policy for Grades 10–12. It is intended to prepare students who have successfully progressed from the General Education and Training phase (Grades R–9) to that of Higher Education (that is, in universities, comprehensive universities and universities of technology) (DoE, 2003b). Furthermore, it is intended to create the basis for lifelong learning and a variety of different career paths (DoE, 2003a). According to DoE (2003a), NCS ensures the development and use of knowledge and skills in ways that are meaningful to the lives of students. In this regard, "the curriculum promotes the idea of grounding knowledge in local contexts, while being sensitive to global imperatives" (p. viii).

The NCS structure and design features include the Subject Statements[2] (DoE, 2003a). For instance, one of the competences the subject of Life Sciences is expected to develop in students in Grades 10–12 is scientific skills (i.e., process skills, inquiry, problem solving and critical thinking skills). In terms of the Life Sciences curriculum, it is believed that these scientific skills can be "best developed within the context of an expanding framework of knowledge" (DoE, 2003b, p. 10). The implication is that, when organising the curriculum, instruction and assessment, teachers are also expected to "provide expanded opportunities for enrichment" (DoE, 2003d, p. 37).

Enrichment learning and teaching has its roots in the theories of Jean Piaget, Jerome Bruner and John Dewey (Renzulli & Reis, n.d.). Enrichments are those learning experiences or activities that are more challenging and go beyond the conventional school curriculum (Renzulli, 1977). Such experiences might include participation in science competitions and practical investigations (Eastwell & Rennie, 2002). A typical enrichment might also encompass activities in which "[a young scientist] becomes an actual **investigator** of a **real** problem or topic by using **appropriate methods of inquiry**" (Renzulli, 1977, p. 29; emphases in the original).

In the Life Sciences in particular, enrichment has long been known as a means of expanding science curricula (Richard, 1969). Enrichment fits well in science education practice because it provides "the students with time, resources and incentives to engage in work on special interest *science research projects*"

[2] Subject statements introduce, *inter alia*, a given subject's (e.g., Life Sciences) key features. These include, the subject's definition, its purpose, scope, educational and career links, and Learning Outcomes

(Kudlas, 1994, p. 33; emphasis added). Eastwell and Rennie (2002) add that many schools offer enrichments and extra–curricular science activities (Chapter 2, pp. 24-25, for the definition and description extra–curricular science activities) to allow bright students to extend their competence. They go on further to say that enrichments and extra–curricular science activities are provided by schools to motivate students who have achieved learning outcomes, in order to continue their participation in science by investigating phenomena beyond the classroom, and to promote the students' understanding of the role and importance of science in their lives. Enrichments thus provide an authentic learning experience, allowing "application of a wide range of cognitive, affective, and motivational processes" (Renzulli & Reis, 2008, p. 6).

In short, enrichments, together with extra–curricular activities, offer a context for the development of skills and knowledge beyond the classroom. ESKOM Expos in South Africa provide such a context.

This study was conducted in the Western Cape Province, one of the nine provinces of the post–1994 South Africa. The Western Cape is among the wealthiest provinces in South Africa, and leads the country in educational achievement. Fiske and Ladd (2005), however, argue that considerable disparities still exists between the quality of educational facilities and human resources (i.e., teachers) offered in the urban areas, as compared to rural and township areas. The Western Cape Province, particularly the Cape Town region, has continuously produced ESKOM Expo participants who have successfully represented South Africa internationally (*ESKOM Cape Town Expo for Young Scientists*, 2007). Alant (2006) argues that the "exclusionary institutional practices of the ESKOM [Expo for Young Scientists]" (p. 180) basically provide opportunities for students from well–resourced schools. However, Rochford (2007) asserts that the sponsor of the ESKOM Expos (i.e., ESKOM[3]) in recent years has focused on increasing the participation of students from historically disadvantaged schools (that is, under–resourced schools) and encouraging them to win awards. Such students are also expected to develop scientific skills and knowledge (*ESKOM Cape Town Expo for Young Scientists*, 2007). Figure 1.1 shows a typical Science Expo in Cape Town. The photo illustrates Expo participants and their exhibitions.

[3] ESKOM is a South African electricity public utility. It was established in 1923 as the Electricity Supply Commission (ESCOM) by the South African government. ESKOM Expo for Young Scientists is one of its current sponsorships.

In the light of this background, the present study researched students' learning through investigative projects in Expos, with the intention of finding out whether the projects enable them to meet the desired educational outcomes within the context of an expanding framework of knowledge, as anticipated by the NCS.

Statement of the problem

The South African science curriculum calls for students who are scientifically literate (DoE, 2002). In the Life Sciences curriculum, such students should be able to:

> Develop [*process skills,*] *inquiry, problem solving* and *critical thinking skills*…and use them to interpret and *use Life sciences concepts* in explaining phenomena. [Moreover, they should be] able to *apply scientific knowledge* in their personal lives and as responsible citizens in ways that will contribute to a healthy lifestyle and the sustainable management of resources. (DoE, 2003b, p. 9; emphases added)

Figure 1.1. A Science Exposition in the Western Cape. From "Photo Gallery" by *Cape Town Expo for Young Scientists* (n.d.*d*)

The curriculum developers believe that students can best develop such skills within the context of an expanding framework of knowledge, for example, of the kind provided by the ESKOM Expos (p. 2). The current study was thus conducted to investigate whether the Life Sciences projects carried out by the students who participated in the ESKOM Expos in the Western Cape Province, South Africa, did indeed promote development of the educational outcomes (i.e., skills and knowledge) stipulated in the Life Sciences curriculum. The study further investigated the students' pertinent experiences that might have influenced possible development of their skills and knowledge.

Aims and objectives

The aim of the study was to explore and analyse Expo students' development of scientific skills and their ability to employ them in interpreting and using Life Sciences concepts to explain phenomena, as envisaged in the Life Sciences curriculum. As 'setting' or context also plays a major role in students' grasp of scientific skills and science concepts/content (Harlen, 1999), and since "learning and understanding involves linking new experiences to previous ones and extending ideas and concepts to include a progressively wider range of related phenomena" (Harlen, 1999, p. 130), a further aim was to investigate Expo–related experiences that shaped the students' learning of Life Sciences through the Expos.

Hence the study, in relation to the Western Cape Province, had the following objectives:-

1. To use Expo reports, a questionnaire and video–based evidence supplied during interviews on Expo students' completed projects, to investigate factors that shaped the students' participation in the Expos.
2. To use the evidence from the project reports, the questionnaires and the interviews of Expo students, to explore:
   (a) The details of the students' performance regarding:
      (i) eleven process skills stipulated in the Natural Sciences curriculum (DoE, 2002), and
      (ii) scientific inquiry and critical thinking skills stipulated in the Life Sciences curriculum (DoE, 2003b).
   (b) The students' understanding of Life Sciences concepts.
3. To use evidence from the project reports, the questionnaires and the student and

mentor interviews, to examine whether there was harmony or tension between the Expos, the science curriculum and science classroom practices in terms of students' development of scientific skills and Life Sciences knowledge.

The study, therefore, set out to investigate the following general research question and three sub–research questions in regard to the Western Cape Province:

How do ESKOM Expos for Young Scientists facilitate the Life Sciences' goal of students' development of scientific skills within the context of an expanding framework of knowledge?

The sub–research questions are as follows:

1. What factors shaped school students' participation in the ESKOM Expo competitions for Young Scientists? (Objective 1)
2. How did Expo projects facilitate the students' development of scientific skills and Life Sciences knowledge? (Objective 2)
3. What articulation occurred between the Expos, the science curriculum and science classroom practices in support of the students' development of scientific skills and Life Sciences knowledge? (Objective 3)

Clarification of terms

In this section, I present definitions of the key concepts used in the study in alphabetical order. Some of these terms or intentions of education are discussed in Chapter 2.

Critical thinking

Critical thinking refers to proficiency in analysis of the arguments presented, in formulating inferences, drawing logical conclusions and critically evaluating all relevant elements, as well as the possible consequences of each decision (King, cited in Chapman, 2001). Critical thinking therefore "applies concepts of logic and reasoning to problem–solving activities in order to produce more accurate and defendable investigation findings" (Philley, 2005, p. 26).

Critical thinking is part of lifelong learning. Students need critical thinking skills when making choices and judgements, as well as evaluations relating to obtaining information, and planning and conducting their scientific investigations. In relation to the latter, critical thinking skills are necessary to investigators in order to:

- identify credibly possible causes;
- evaluate evidence in support of (or to refute) a proposed cause scenario hypothesis;
- identify the need for additional specific evidence to confirm or refute a proposed cause scenario; and
- select the most appropriate scenario (Philley, 2005, p. 26).

Investigations and research projects

Investigations in a school context are a specific type of problem solving, defined as “a task for which a pupil cannot immediately see an answer or recall a routine method for finding it” (Gott & Duggan, 1995, p. 14). Woolnough (1994) argued that scientific investigations might take the form of extra–curricular science activities such as student research projects. Indeed, in Science Fairs or Expos, such projects are defined as “[investigations] of a question that involves research, planning, and application of the scientific method to find the answer” (Fontichiaro, 2010, p. 5). Woolnough (1994) observed that for students, in particular, the projects:

- establish the pinnacle of their work in school science;
- enable them to produce novel in–depth scientific investigations of the highest standard, and give a sense of personal achievement essential to developing their self–confidence in and motivation to do science at school;
- enable them to discover or “bring together many of their personal attributes, such as creativity, perseverance and co–operativeness, along with their scientific knowledge and skills” (p. 47); and
- provide them with the experience of learning scientific method/process and, as a the result, join the élite (that is, by partaking in the same type of activity as professional scientists).

Learning Areas/Fields

The subjects in the NCS are categorised into Learning Fields (DoE, 2003a). The following is an example of a subject grouping, demarcated in the FET phase, which aimed to help students with their subject combinations: Physical, Mathematical, Computer, Life and Agricultural Sciences (DoE, 2003a). In this study, these subjects (which are in fact linked to specific occupational categories [DoE, 2003b]) are referred to as Learning Areas. They include, for instance, the Learning Areas of *Life Sciences* and *Physical Sciences*. Each Learning Area is defined by its Learning Outcomes (DoE, 2003b).

Learning Outcomes

Learning Outcomes are statements of intended results of learning and teaching. They describe the "*knowledge*, *skills* and *values* that learners should acquire by the end of the Further Education and Training band" (DoE, 2003b, p. 7; emphases added). As the learning outcomes (p. 14) are associated with what students should know, demonstrate or be able to do, they also cater for students' competences in the utilisation of appropriate scientific skills and knowledge in investigative projects or extended investigations such as the Expo projects.

Project categories

Project categories refer to different groupings in which student projects are accommodated, and are aligned with the judges for the judging process. In South Africa, Expos have 25 different categories for primary and junior school entrants (Grades 6–9) and senior school entrants (Grades 10–12), such as animal and plant sciences, health care and medicine (*ESKOM Cape Town Expo for Young Scientists*, 2007; *Cape Town Expo for Young Scientists*, n.d.*c*).

The subject of Life Sciences caters for careers, such as *medicine*, *bioengineering* and *nursing* (DoE, 2003b). The current Expo projects categorised under health care and medicine were thus suitable for the present study, which was specifically focused on Life Sciences projects.

Science Fair

A Science Fair is an event at which contestants' "science projects are both celebrated and evaluated" (Bencze, Bowen, & Arsenault, 2008, p. 2) in relation to the given scientific standards (Bochinski, 1991). It provides contestants with "educational opportunities for exchanging and learning new scientific methods and concepts with professionals and other contestants" (Bochinski, 1991, p. 9). The associated science projects offer the contestants opportunities to gain hands–on experience in exercising their process skills and knowledge in novel in–depth scientific investigations in various fields of study, such as for example medicine (Bochinski, 2004).

Countries other than South Africa hold science competitions or extra–curricular science activities comparable to Science Fairs; these include, for instance, the Science Talent Search (Tytler, 1992) in Australia, the Science Olympiad (Abernathy & Vineyard, 2001; O'Kennedy *et al*., 2005) in the United States and Ireland, and the Science Exposition (Gray & Nchesi, 2004) in Malawi. The present study is focused on the South African ESKOM Expo for Young Scientists (p. 17).

Science process skills

Science process skills are activities that scientists carry out when they study or investigate a problem, an issue or a question (Rambuda & Fraser, 2004). They are thus "…*creating meaning* and structure from *new information* and *experiences*" (DoE, 2002, p. 13; emphases added). Drawing on DoE (2002), these skills are applicable to the learning outcomes of the science curricula; they include observing and comparing, measuring, recording information, sorting and classifying, interpreting information, predicting, hypothesising, raising questions about a situation, planning science investigations, conducting such investigations, and communicating science information. The literature framed around such process skills is presented and reviewed in Chapter 2.

Scientific inquiry

Scientific inquiry refers to the diverse ways in which scientists study the natural world and how they propose explanations based on the evidence derived from their work. It also incudes the activities of students through which they develop a knowledge and understanding of scientific ideas, as well as an understanding of how scientists study the natural world (Cuevas, Lee, Hart, & Deaktor, 2005).

Active, meaningful and high–level learning are attributes of inquiry learning (Wilke & Straits, 2005). The knowledge and skills essential to carrying out scientific investigations, as advised by Wilke and Straits (2005, p. 535), are presented in Table 1.1.

Table 1.1

Scientific knowledge and scientific skills essential to conducting scientific inquiry (Wilke & Straits, 2005)

Factual information	**General process skills**	**Scientific method skills**	**Experimental design skills**
This encompasses discipline-specific knowledge.	Observing, classifying, designing, drawing, writing, measuring, predicting, inferring, analyzing, applying, summarizing, communicating, evaluating, synthesizing, creating, and problem–solving.	Asking questions, proposing hypotheses, making predictions, designing experiments, collecting and analyzing data, drawing conclusions, interpreting evidence, building models, and making judgements.	Identifying: sources of error, variables (control/dependent/ independent), appropriate materials, and limitations.

Scientific knowledge/science content

Rillero (1998) defined science content as "the body of knowledge generated from scientific enquiry" (p. 3). He held that science content complements the process skills of science, so both are equally important in scientific investigations. He argued that, while process skills steer the processes of science, promote understanding of science and help students to appreciate the origin of facts, science content is the 'knowing' of science. It provides a stage for further explanations and hence understanding of many aspects of the world. It offers "insights into the working of the universe, the *biosphere* and the *human body*" (emphases added; Rillero, 1998, p. 3).

Context of the study

Many educational strategies emphasise a more learner–centred education system (Taylor, Vlaardingerbroek, & Coll, 2003). Cutler (2004) adds that the trend has been towards teaching knowledge and an understanding of how science works through developing key skills and thinking skills in the school science curriculum. These skills, which have become an integral part of classroom teaching and learning, include communication, working with others, reasoning, enquiry, creative thinking and evaluation. Cutler's (2004) assertion regarding the skills, knowledge and understanding of school students is supported by the South African Life Sciences curriculum (p. 4).

In the next sub–section, I provide an overview of curriculum reforms in South Africa, and its requirements relating to its principles. An overview of the ESKOM Expos for Young Scientists will also be presented, as they provide a context for the expanding framework of knowledge advocated by the National Curriculum Statement (NCS) for Life Sciences (DoE, 2003b).

Overview of curriculum reforms in South Africa

The underlying philosophy of the South African curriculum reforms embodied by *Curriculum 2005 (C2005)* launched in 1997, was an outcomes–based approach to education and learning (Botha, 2002; Todd & Mason, 2005). The rationale for the reforms (that is, from the content–based educational system of the apartheid era to an outcomes–based education driven by *C2005*) was that South African students had for too long been subjected to 'cookbook' approaches associated with the memorising of content, which they were required to reproduce in tests and examinations (Hattingh, Rogan, Aldous, Howie, & Venter, 2005). A student–centred and activity–based approach to education needed to be implemented (Harley & Wedekind, 2004). Harley and Wedekind (2004) assert that OBE – the design feature of *C2005* – became synonymous with *C2005*. OBE thus became part of the social transformation of South African post–apartheid society, in which the former disadvantaged majority could be empowered (DoE, 2003b). OBE strived to "prepare young South Africans for a globally competitive and technologically sophisticated economy" (Todd & Mason, 2005, p. 222).

OBE can be defined as an education system that strives for a learner–centred and activity–based approach to learning. It does this by focusing and organising everything around "what is essential for all students to be able to do successfully at the end of their learning experiences" (Spady, 1994, p. 1). The outcomes thus become indicators of a student's proficiency in utilising science content, scientific skills, ideas, and various forms of information, as well as the necessary tools (Spady, 1994).

With the paradigm shift to OBE, the focus is now on students' competency, that is, on what they can do with their knowledge and, more importantly, whether they can use what they know to meet the learning outcomes (Hattingh *et al*., 2005). With regard to OBE, it is important that conditions are in place to enable *all* students to achieve successful outcomes at the end of their learning experiences (Spady & Marshall, 1991). Furthermore, there is a need for suitable curriculum design, instruction and assessment, to make sure that this learning ultimately happens

(Botha, 2002; DoE, 2003b; Spady & Marshall, 1991). It is envisaged that, with these basic premises of OBE in place, the final product will be citizens who are critical, investigative, creative, adept at problem solving, communicative and future–oriented (Botha, 2002; DoE, 2003b).

A number of South African researchers, however, had already raised concerns directed at OBE while it was being implemented. At the forefront was undoubtedly Jonathan Jansen. His paper, "Curriculum Reform in South Africa: a critical analysis of outcomes–based education [1]" (1998) became the focal point of debates on *C2005* and OBE. In this paper, Jansen (1998) predicted that OBE would fail in South Africa. He believed that its failure would be rooted in its flawed policies, "driven in the first instance by political imperatives which have little to do with the realities of classroom life" (p. 323). Jansen's (1998) assertions regarding the new curriculum in relation to the realities of classroom life were supported by Todd and Mason (2005), in which they contended that OBE had limited potential for enhancing learning in schools which lacked the capacity to implement it. Other critics of *C2005* and OBE include Zinn (2000) and Waghid (2001). Zinn (2000) raised some challenges about disparities between schools in terms of information literacy and OBE in the 21st century. These included, for instance, the shortage of learning support material needed to effectively implement OBE, and the limited number of schools that have at least one computer. Waghid's (2001) critique was based on an examination of critical outcomes and of specific outcomes in relation to students' rational reflection and imagination. According to him, given the fact that "outcomes seem to be heavily attuned to control and manipulation, it makes the instrumental justification of the approach without reflection and imagination somewhat a predictable education tragedy" (p. 132).

As the implementation of *C2005* was clearly a key area that needed to be addressed, the Ministry of Education commissioned a review in 2000. However, as Harley and Wedekind (2004) pointed out, "the Review was constrained by its brief 'to review Curriculum 2005 and not outcomes–based education'" (p. 214). As a result, OBE has been included in the transition from *C2005* to the National Curriculum Statement (NCS).

The National Curriculum Statement for Life Sciences is the focus of the present study. The NCS has not escaped controversy over its implementation of OBE. Indeed, the former University of Cape Town vice–chancellor and World Bank director Mamphela Ramphele asserted that the South African education system must be overhauled and OBE done away with because it failed to meet the nation’s expectations, as has also been the case in Canada, the Netherlands, New Zealand, and the United Kingdom (Smook, 2008). More recently, Taylor (2010) not only raised some conceptual and factual errors in “the curriculum and assessment policy statements for science” but also pointed out the “new” curriculum’s inclination towards rote learning at the expense of critical thinking and an inquiry approach (p. 43).

The NCS was implemented in 2006, starting with Grade 10. It was subjected to a review at the time of the current study in order to strengthen its implementation (Motshekga, 2010). The review was completed in September 2009. This “old” NCS can still be used as a yardstick.

The NCS requires that students taking Life Sciences be able to develop and use process skills, scientific inquiry and problem–solving skills (Table 1.2) within the context of an expanding framework of scientific knowledge (DoE, 2003b). This implies that such skills cannot be developed in isolation of content (DoE, 2003b). The students’ understanding of scientific concepts and their performance of scientific processes are equally important, since many skill–type performances depend upon knowing and understanding the relevant content (So, 2003).

Table 1.2

Scientific skills stipulated by the National Curriculum Statement Grades 10–12 (General) for Life Sciences (DoE, 2003b)

Scientific inquiry, problem solving and critical thinking skills	
Data handling skills	**Experimental skills**
Identifying Selecting Organising Presenting Translating Manipulating data Making inferences Deductions and conclusions from data gathered	Following instructions Making observations Measuring trends Recording information

As presented in the National Curriculum Statement for Grades 10–12 (General) of the Further Education and Training phase (FET), the subject of Life Sciences develops the competences set out below.

Learning Outcome 1: Scientific Inquiry and problem–solving skills:
The student in the FET phase will be able to “confidently explore and investigate phenomena relevant to Life Sciences by using inquiry, problem solving, critical thinking and other skills” (DoE, 2003b, p. 12).

Learning Outcome 2: Constructing Science Knowledge:
The student will also be able to “access, interpret, construct and use Life Sciences concepts to explain phenomena relevant to Life sciences” (DoE, 2003b, p. 12).

Learning Outcome 3: Science, Society and Knowledge:
Furthermore, the student must be able to “demonstrate an understanding of the nature of science, the influence of ethics and biases in the Life Sciences, and the interrelationship of science, technology, indigenous knowledge, the environment and society” (DoE, 2003b, p.12).

In investigating students’ competences regarding, for instance, scientific skills (e.g., process skills), it is important to provide an illustration of the development of the skills in Life Sciences in South African classrooms.

The poor performance of South African schools compared to those of both the developed and developing countries has been documented by researchers, such as Reddy, Kanjee, Diedericks, and Winnaar (2006). Reddy *et al*. (2006) showed that there had been no significant change in science (e.g., Life Sciences) achievement between the Trends in International Mathematics and Science Study (TIMSS) of 1999 and that of 2003 (TIMSS 2003 was held in South Africa in 2002). This suggests that the South African students’ development of factual and conceptual knowledge, analysis, reasoning skills, and process skills had remained poor.

De Jager and Ferreira (2003) examined the latter within the context of the Life Sciences curriculum. They argued that, although the development of process skills, in particular, is emphasised in Natural and Life Sciences, “it is often neglected in the South African classroom” (p. 186). They went further to argue that the implementation of a process approach (Chapter 2, pp. 41-42), essential for the development of science process skills in Life Sciences classrooms, had been neglected. Key factors contributing to this neglect included an inflexible and irrelevant biology curriculum and a lack in the curriculum of clearly stated outcomes related to process skill development. They argued further that “many teachers may not be familiar with the concept of process skill development and therefore do not pay attention to the cultivation of these skills" (p. 187). De Jager and Ferreira (2003) also asserted that another possible explanation for the neglect of process skills in the Life Sciences classrooms might be that the teachers had developed these skills without always consciously emphasising them. These findings could also imply that any practical activity to which students were exposed in Life Sciences might be of the 'cookbook' style. Indeed, Muwanga-Zake (2003) has questioned the scientific value of practical work in South African classrooms. He reasoned that Life Sciences experiments simplify otherwise very complicated processes, making them unexciting as science activities. Moreover, many teachers preferred imparting knowable facts, particularly those taken from books, to their students, and often such teachers either did not use, or seldom used, available science equipment because of their own lack of practical skills or conceptual understanding of science. Hobden (2005) also noted problems in the Physical Sciences classrooms, where "taking Physical Science essentially involved watching and listening how to solve problem tasks followed by practice on numerous similar ones in preparation for examinations" (p. 308). De Jager and Ferreira (2003) suggest that teachers should adopt different methods of teaching and learning, framing their strategies around a process approach. Indeed, they go further, suggesting that teachers, especially those in rural areas and townships, might benefit from guidance on involving their students in scientific investigations.

It should be noted, however, that the policy of emphasising the development of process skills by school science students has been criticised in the past. Millar and Driver (1987), for instance, raised important questions about the validity of a process skills approach to the curriculum. On the one hand, they stated that a process approach placed emphasis on the dynamic aspects of science in such a way that students could discover meaning, and they acknowledged such learning as an active process. Nevertheless, they also argued that a process skills approach is divorced from the students' own prerequisite knowledge and skills relating to learning activities. This approach further casts doubts on its effectiveness, because pedagogically it reflects the contested didactic portrayal of scientific knowledge as absolute and unproblematic. Millar (1989, 1991, 1997) and Wellington (1989) also criticised the favouring of process skills which could be applied in novel contexts, such as in the South African Expos.

As Bentley, Ebert and Ebert (2007) eloquently put it, students' development and refinement of science process skills has proved to be *the* educational challenge.

Arena (1996) also warned us that research has shown that while secondary students are cognitively mature enough to cope with the more advanced process skills, they seldom perform well.

Studies in China by Yip (1999) and So (2003) provided additional insights to the findings in de Jager and Ferreira's (2003) study in relation to school students' development of process skills through investigations. It should be noted that the top performing countries in the TIMSS 2003 included Hong Kong (Reddy *et al*., 2006). Yip (1999) examined several school science curricula and concluded that classroom–based investigative work by students had formed the basis for learning. He argued that, once they had been exposed to activity–based and student–centred approaches involving investigations, the students were expected to be proficient in the concepts and skills of collecting and evaluating evidence which are essential to understanding the process of scientific inquiry and the nature of science. However, the students remained poor at planning and conducting proper scientific investigations. Yip (1999) reasoned that teachers were inclined to use out–of–date methods, in which students were provided with full instructions on the execution of an investigation, rather than providing educative experiences conducive to the design of their own investigations using school projects. Yip (1999) went further to say that "many teachers are not themselves equipped with adequate *knowledge* and *skills* to teach investigative work" (p. 204; emphases added). Indeed, his study in China, in which 45 A–level biology teachers enrolled in the Postgraduate Diploma in Education were assessed on their ability to draw conclusions from experimental results, articulated his arguments. Although Yip (1999) designed a strategy to help the teachers acquire the necessary skills and knowledge, they were challenged with regard to clear understanding and a consistent rationale for identifying the control in different experimental situations.

So (2003) conducted research aimed at developing an understanding of school students' learning through investigative projects at primary level. The study also investigated the interplay between the students' understanding of the scientific concepts and the details of their performance regarding science process skills, using 24 written records of the students' investigations. So (2003) concluded that, in the innovative and multicontexual projects she evaluated, the students viewed their studies as teaching them both content and procedures. However, their appreciation of the relationship between their own empirical data and wider scientific theory was not extensive, probably because of the age of the students selected.

Overview of ESKOM Expo for Young Scientists

In South Africa, extra–curricular science activities that are more challenging and go beyond the conventional curriculum include the ESKOM Expos for Young Scientists. These Expos are held in approximately 26–28 regions of South Africa in August each year. Participants are school students in two categories: primary and junior school entrants (Grades 6–9) and senior entrants (Grades 10–12). The Expos are thought of as a vehicle for enhancing South Africa's economic prosperity and future (*ESKOM Cape Town Expo for Young Scientists*, 2007). Indeed, Expos encourage both primary and high–school students to study science at tertiary level. The students are encouraged to relate the mastery of science to real life career options, such as medicine, engineering, or architecture. Expos thus attempt to ensure that continued growth and development of the lifestyles of young South African scientists is sustainable (*ESKOM Cape Town Expo for Young Scientists*, 2007).

Expos encourage and develop potential young scientists, technologists and mathematicians, especially those who are able to identify a new problem, analyse information, find solutions and communicate their findings effectively (*Mission statement*, *n.d.*). They offer a stage on which successful school students can demonstrate their inventive and innovative skills in the fields of science and technology with personalised "projects that have been well researched, are original and innovative, and can be utilised to better the country" (*ESKOM Cape Town Expo for Young Scientists*, 2007, p. 4). The projects provide opportunities to proceed, on merit, from regional to national competitions and, ultimately, to participate in the international science Expos. ESKOM Expos are thus among those non–profit institutions in South Africa which strive to increase the availability of scientists and researchers in the South African scientific field. They have been hailed as useful avenues for opening up students' horizons in science and technology, and hence of advancing scientific literacy in accordance with the principles of OBE at a more advanced level (Alant, 2006; Molefe, 2003).

Expos and their associated activities thus provide a context for enrichments and/or extra–curricular science activities. The literature framed around extra–curricular science activities, Science Fairs, Expos and the development of educational outcomes (i.e., scientific skills and knowledge) is reviewed in Chapter 2.

Research design and the study's logic model

A qualitative research approach was utilised to investigate details of the Expo students' performance regarding process skills and their Life Sciences knowledge. This approach also entailed recording the students' biographies – these were essential to documenting the factors that shaped their participation at the 2007 Expos. The research design employed was therefore that of a multiple case study. The cases were purposefully selected from a pool of Expo participants at the Expo venues (that is, Cape Town and Stellenbosch).

I have adapted the generic logic model (Program Action–Logic Model, *n.d.*) below (Figure 1.2) to outline what the present study involved and what it has accomplished (further details are provided in Chapters 3 and 5).

The originating problem

As referred to earlier (pp. 4-5), the problem of the present study was framed around ESKOM Expos in the Western Cape Province and their role in promoting development of the educational outcomes stipulated in the Life Sciences curriculum, as well as the students' own pertinent experiences.

The research base

Five individual Expo entrants, together with existing data (Expo project reports), were used as the base for the study. The cases comprised students from Grades 10-11 who took part in the 2007 ESKOM Expos held at the two main Expo venues in the Western Cape. The students were from three schools in the Province.

The data collection tools and the associated participants

The data collection strategies used included semi–structured interviews and document analysis. The interviews were used to explore and document the Expo students' experiences relating to the Expos and their developed skills and knowledge. Semi–structured interviews were also used with the students' mentors. These were intended to substantiate and/or add to the students' reports on their own science learning experiences in their respective schools. The students' project reports and completed semi–structured questionnaires constituted the documents that were analysed in order

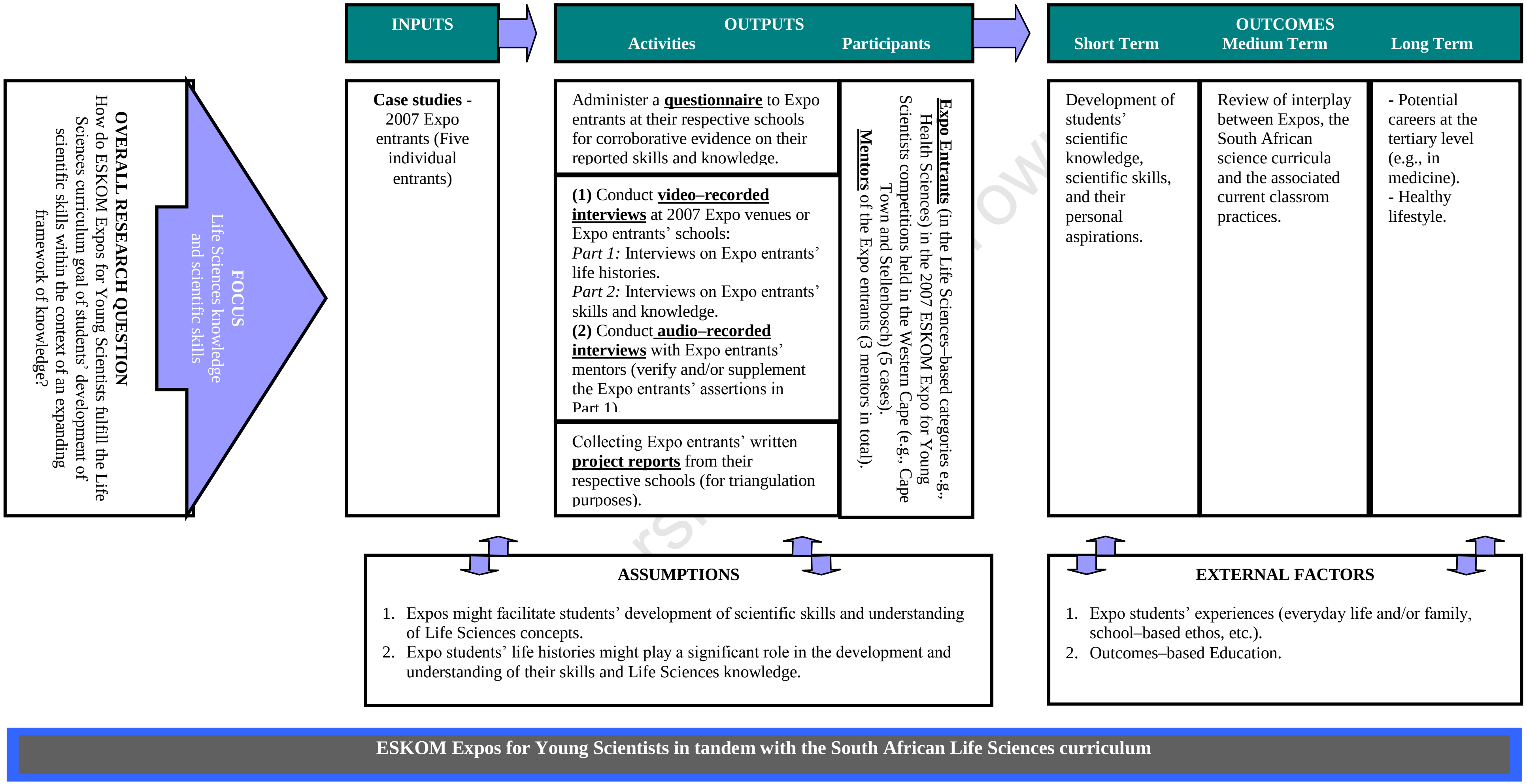

Figure 1.2. The present study's logic model. Adapted from *Program Action–Logic Model* (*n.d.*)

to assess the participants' developed skills and knowledge. Their Expo reports, interviews, and the questionnaire data were used for triangulation purposes. All the interviews were subjected to thematic analysis. The students' project reports and the completed questionnaires formed the basis for document analysis. Holistic analysis of the results from the reports, interviews and the questionnaires was also made.

Assumptions

The curriculum developers in Life Sciences stipulated the kind of a context in which students could best develop scientific skills (p. 2). Given this, it was assumed that, as Expos provide such a context, they might develop these educational outcomes. Furthermore, as this study was framed on the case study research design, the students' experiences relating to the Expos were assumed to be essential.

External factors and the results

The students drew upon their everyday life experiences, both at home and at school, to investigate biological phenomena. The educational outcomes of the research included their development of scientific skills and Life Sciences knowledge. The study showed that the students' research projects form the basis of a successful interplay between Expos and the Life Sciences curriculum. Moreover, it also showed that both Expos and Life Sciences encourage exploration of educational and potential career opportunities.

Delimitations of the study

The study was restricted to the process skills and Life Sciences knowledge of a volunteer sample of high–school students who presented their investigative projects in ESKOM Expos held at Cape Town and Stellenbosch in 2007. The study was thus restricted to the Expos in the Western Cape, South Africa.

The researcher's expertise is in Life Sciences. The study was therefore demarcated from the other Learning Areas available at the Expos, such as Physical and Mathematical Sciences.

The study was also limited to the abovementioned sources of data and information. The student volunteers were not observed as they engaged in practical work related to their respective investigations because students who participate in the Expos are protective of their work/projects *prior* to the Expos. Most of the participants were not willing to share their work in Expo reports with me, even *after* the competitions. As a result of this challenge, the study was also demarcated from other categories found under Life Sciences in the Expos, such as plant and animal sciences.

Organisation of the remainder of the study

The next four chapters of the thesis are arranged as follows:

In Chapter Two, I introduce the relevant literature review in two parts. The first part deals with the literature regarding extra–curricular science activities, which includes Science Fairs, Science Expositions, and the associated investigative projects. The process approach and/or activity–based approach to teaching, learning and assessment in relation to the scientific skills development is then reviewed in the second part. Also included here are the rhetoric debates and research findings relating to scientific processes and skills.

Chapter Three deals with the details of the research methods. It describes, and provides a rationale, for the research design and data collection. The data were collected over two phases: (a) the pilot phase, which encompassed the stages related to development of the data collection tools used; (b) and the implementation phase, in which the developed tools were used. The chapter presents a description of the procedures for data collection over the two phases, and the subsequent analysis of the data.

Chapter Four provides a detailed account of the data analyses and results obtained from triangulated responses of the Expo students, which relate to the study's research questions. The chapter is divided into two key sections. The first section is framed around the Expo students' biographies and the associated themes that represented factors which shaped their participation in Expos. The second section presents results of the details of the students' performances regarding process skills and their Life Sciences knowledge.

In Chapter Five, the research questions of the study and its design are reiterated. The limitations of the study are also given. The chapter continues with discussions of the answers to the study's research questions. These are followed by a discussion of the significance of the study, recommendations for further research, and concluding comments.

CHAPTER 2

REVIEW OF LITERATURE

Introduction

This chapter will be presented in two parts. The focus of the chapter will be framed on research and literature based on extra–curricular activities in science, and science process skills.

There is a body of literature that reports science curricula efforts on rethinking what school students learning science should know and what they should be able to do. In the South African Life Sciences, ordinary students are expected to develop scientific skills, and use them to interpret and use Life Sciences concepts in explaining phenomena when they learn through scientific investigations. However, if ordinary science classrooms are producing students that are not sufficiently competent in terms of their conception of scientific skills and concepts, how do students whose scientific skills are developed within the context of an expanding framework of knowledge (i.e., extra–curricular activities in science) compare? The **first part** of the chapter is thus focused on school students learning through investigations in *extra–curricular science activities* (p. 25, for definition), the associated students' competence in scientific skills, and their development of desired educational outcomes in such a context.

The above expectations of the South African Life Sciences regarding scientific skills and Life Sciences concepts suggest that there is the interplay between ordinary students' understanding of *scientific concepts* and the details of their performance of *process skills*. Indeed, the South African Life sciences curriculum clearly shows that the systematic study of life in the changing natural and human–made environment by students involves critical inquiry, reflection, and the understanding of concepts and processes and their application in society. Hence, the **second part** is focused on process approach and/or activity–based approach to teaching, learning and assessment in relation to the scientific skills development. Also included are the rhetoric debates and research findings related to scientific processes and skills.

PART 1: LEARNING SCIENCE THROUGH EXTRA–CURRICULAR SCIENCE ACTIVITIES

School science should extend beyond classroom to be relevant to the students' lifeworlds and provide them with opportunities to learn and grow. Extra–curricular science activities, such as Science Fairs provide such opportunity. Indeed, in the South African science curricula, these extra–curricular activities provide a context of an expanding framework of knowledge. Consequently, in this part I review literature and research on extra–curricular science activities and their role in the school students' development of educational outcomes, such as scientific skills and knowledge. Firstly, extra–curricular science activities will be defined. Then, the rationale for students' competence in the skills would be reviewed. A review of related issues in the context of extra–curricular science activities, such as Science Fairs and Science Expositions, in tandem with science curricula, will also be provided.

Extra–curricular science activities

Historical development of extra–curricular activities could be traced as far as ancient schools (McKown, 1940). McKown (1940, p. 2) argued that "it is practically correct" to say that their recent development is embedded in the American college system during the nineteenth century. In South Africa, developments of these activities might be traced as far as the new outcomes–based education (OBE) system. OBE puts emphases on teachers' Learning and Teaching Support Materials to provide expanded opportunities for enrichments (DoE, 2003d), and on the further development of scientific skills in a wider context (DoE, 2003b; DoE, 2003c).

The definition of enrichments has been given in Chapter 1 (p. 2). On the other hand, an explicit definition of extra–curricular activities had been a problem (McKown, 1940). However, a number of researchers have provided their perceptions of what constitute an extra–curricular activity. Mahoney, Cairns, and Farmer (2003) qualified an activity as extra–curricular if it promotes interpersonal competence and is characterised by "voluntary participation, structure, and challenge" (p. 410). Holloway (2002) argued that such activities should:

- Appeal to students' (including minorities and women) curiosity.

- Connect students to school.
- Build student–mentor relationship.
- Promote peer interaction, as well as cooperation.

In science, extra–curricular activities also form a broad category that is not easily defined (Woolnough, 1994). Woolnough qualified them as activities extra to the basic science curriculum or important part of assessment, and are recognised by, for instance, competitions and student research projects. Other factors embedded in these activities include, *inter alia*, a challenge of students' imagination and inducing their creativity and innovation. The activities also promote the development of students' talents and the associated public recognition.

Drawing from the above review, extra–curricular activities in science or extra–curricular science activities might, therefore, be defined as those activities associated with learning beyond the classroom. Students' participation in the activities is both voluntary and compulsory. In these activities, development of students' competence is nurtured through interpersonal relations both at school and through participation in science competitions (e.g., Expos). The students are expected to be able to act on their curiosities and subsequently develop their scientific skills and concepts through projects of their choices. Designing and completing the projects might be a steppingstone to their school educational achievement and future careers because they might develop the science students' exceptional competence in scientific skills.

The importance of students achieving skills competence in school science

Competence in basic skills has become part of the emphasis and challenge of current science education. Coupled with this was advocacy of, *inter alia*, more investment in human resources, innovations in teaching and learning, and bringing learning closer to home (Briede, 2004). Furthermore, regarding the acquisition of more complex skills, science education reformers in the United States have argued that citizens' command of key scientific ideas, their ability to solve problems, and their critical thinking should also be the fundamental part of this post–industrial, information economy (Marx, Blumenfeld, Krajcik, & Soloway, 1997). Statter and Tamir (1998), in their research study in Israel, suggested a way to provide a perfect opportunity to develop high school students in Life Sciences throughout their studies and throughout their lives. They asserted that "the research project, and particularly *research project in biology*, enables the high school student [not only] to acquire the skills of an independent student" (p. 220; emphasis added) but also mould them into competent lifelong learners.

Briede (2004) elaborated on the concept of competence with regard to lifelong learning. Briede acknowledged the notion of "a humanistic model of learning in which a student–centered approach promotes independent individual work and reflective action" (p. 11). It was envisaged that the students in this context would be provided with the opportunity to improve their own learning, develop skills, perform, present evidence and exercise reflection. This concept within the South African outcomes–based education is associated with developing the kind of students that can reach their maximum potential and are equipped for lifelong learning. Emphasis is mainly on the development of a high level of knowledge and skills in students, which will allow them to choose different directions in the lifelong learning (DoE, 2003b). It is believed that the skills will enable students grow into citizens that are able to cope with the demands of life (Kotzé, 2002). It is envisaged that the student will be, for instance, informed, confident and independent, multi–skilled, compassionate, with respect for the environment and has the ability to participate in society as a critical and active citizen (DoE, 2002).

Consequently, in can be concluded that, it is important that students develop their competency in scientific skills, such as science process skills and critical thinking skills, in variety of settings. Emphasis should also be focused on the development and application of scientific knowledge and understanding; understanding the interrelationships between science, technology, society and the environment, and students' will power; their courage as well as their experiences. All these issues constitute the concept of competence in general (Jensen & Schnack, cited in Briede, 2004; DoE, 2002; DoE, 2003b). In order to achieve this competence, students should be given opportunities to actively engage, mentally, emotionally, physically in minds–on and hands–on practices aiming at acquisition and development of abilities and competence related to aspects of the scientific investigation process (Gomes, Borges, & Justi, 2007). Abernathy and Vineyard (2001) suggested that educators should encourage "activities that appeal to different types of students" (p. 276). According to them, the activities include Science Fairs.

Science Fairs

There are many science competitions in the world today that strive to encourage school students to learn about science (O’Kennedy *et al*., 2005). However, Science Fairs in particular, and their associated science projects, are both celebrated and evaluated globally, and both have a rich and long history (Bellipanni & Lilly, 1999; Bencze, Bowen, & Arsenault, 2008; Bencze & Bowen, 2009a). In African countries such as Malawi (Gray & Nchesi, 2004) and South Africa (Alant, 2006; Molefe, 2007, 2008; Parker & Rochford, 1995; Rochford, 1998, 2007), Science Fairs take forms of Science Expos. Hence, the focus of the review of literature will be on the Expos because they are extra–curricular science activities (Rochford, 1998, 2007) as much as the Fairs (Bencze & Bowen, 2009a; Robinson, 2003). Furthermore, similar to Science Fairs – which are relevant to science curricula goals (Bellipanni & Lilly, 1999) – Expos provide a context for an expanding framework of knowledge in the South African science curricula (Molefe, 2007, 2008).

Before I address the Expos within the South African context, it is imperative that I present overview of distinctive features of Science Fairs. A definition of Science Fair is provided in the previous chapter (Chapter 1, pp. 8-9).

How Science Fairs are operated

Science Fairs have operative rules (Abernathy & Vineyard, 2001). For instance, Science Fairs encourage individual investigative research projects (Jones, 1991), which form the basis for authentic scientific or technological experiences (Gray & Nchesi, 2004). Teachers and parents of the participants prepare them for such experiences (Abernathy and Vineyard, 2001) in different ways. The projects, which the students carry either within or outside of the context of their schooling, provide a passport to participation at regional, national or even international level depending on the merits of the projects (Bencze & Bowen, 2009a; Bencze, Bowen, & Arsenault, 2008). There are three implications for science education practice related to the abovementioned issues of context and the projects’ merits. Firstly, the projects may be compulsory (Abernathy & Vineyard, 2001; Bunderson & Anderson, 1996; Czerniak & Lumpe, 1996) with teachers’ involvement more of an obligation than interest, or they may be voluntary (Statter & Tamir, 1998). Secondly, students from different grades *can* participate (Bellipanni & Lilly, 1999). Thirdly, there are Science Fair judges, often “teachers, college/university faculty, physicians, engineers, or others with interest in [Science Fairs programmes]” (Abernathy & Vineyard, 2001, p. 269), who determine the merits of the projects. Drawing on Robertson (2007) and Rodia (2004), it can be concluded that such merits may include (or not limited to) understanding the scientific investigation. Hence, students may be judged in relation to: (a) developed innovative and creative skills associated with creating, executing, and presenting one's project; (b) developed understanding of the nature and relevance of science, and the scientific method; and (c) proficiency in defending the subsequent project, which may encompass best presentation and the associated critical thinking skills. These merits might be the important deciding factor for success at the exhibitions centres, but to educators they are viewed as means for students to achieve goals essential in science education practice (Abernathy & Vineyard, 2001). For instance, educators may view the merits as indicators of whether students have demonstrated competence in a given number of learning outcomes (e.g., students' competence for developing logical plans to conduct fair testing or pattern seeking type of investigation).

Science Fairs goals and the associated learning outcomes

Learning Outcomes in science are based on (but not limited to) the following competences: (a) scientific skills (e.g., making observations, manipulating data, etc.), and (b) construction and application of knowledge (DoE, 2003b). For Woolnough (1994), students' competences or educational outcomes include skills, knowledge and understanding, and attitudes. Science Fairs can enable development of these educational outcomes (e.g., Czerniak, 1996; Schneider & Lumpe, 1996). Indeed, Abernathy and Vineyard (2001) stressed that proponents of Science Fairs consider learning science process skills and science content as their true purpose. Hence, it is not surprising that "the primary goal of a science fair is to complement school curricula by encouraging students to use and understand the scientific method in designing and performing experiments" (Abernathy & Vineyard, 2001, p. 270), and stimulate their interest in science and/or engineering (Bellipanni & Lilly, 1999; Grote, 1995). Students are expected to be able to identify problems, propose solutions, conduct fair tests, analyse data and draw conclusions (Bellipanni & Lilly, 1999). In addition to the abovementioned skills, Science Fairs also play a major role in building students' competence in communication skills, and learning the nature of science (Abernathy & Vineyard, 2001). The students are also provided with an opportunity to develop research skills and a "high degree of technical knowledge" (Galen, 1993, p. 466), when participating in these Fairs. Science Fairs also cater for the social domain and personal development in that they may induce sense of responsibility and purposefulness in students, as well as sense of personal capabilities and qualities (Balas, 1998).

It is evident, therefore, that the following specific learning outcomes could also be expected from the meaningful learning experience of students through participation in the Fairs:

- Development of attitude towards science (Czerniak & Lumpe, 1996; Wilson, Cordry, & Uline, 2004). For instance, autonomy, pride in work (Woolnough, 1994) and commitment (Abernathy & Vineyard, 2001; Woolnough, 1994). Furthermore, participation may increase students' interest in science (Balas, 1998; Bunderson & Anderson, 1996; Grote, 1995) by stimulating the students' innate curiosity and setting a new context, divorced of inflexible curriculum, for them to learn like the real scientists (Abernathy & Vineyard, 2001). The students may "share the fun of doing science, playing with science, and exploring new fascinating phenomena" (Woolnough, 1994, pp. 92, 95).
- Broadened conception of science (Coskie & Davies, 2007). For example, students may learn about "some characteristics of science, including its competitive nature" (Bencze, Bowen, & Arsenault, 2008, p. 4).
- Broadened scope of subject matter knowledge (Bencze & Bowen, 2009b). Students get involved in "developing and using science skills and scientific reasoning to build new content knowledge" (Abernathy & Vineyard, 2001, p. 269). Their prior knowledge and the new content knowledge become instrumental in generating, analysing, and assessing the impact of their results, as well as relating what they learn to experiences beyond their projects (Balas, 1998).
- Development of skills. Students developed skills may include process skills that encompass "technical skills, such as measurement techniques" (Bencze, Bowen, & Arsenault, 2008, p. 4), creativity (Bunderson & Anderson, 1996), and other skills (e.g., social skills [see Olszewski–Kubilius & Lee, 2004]).

Critique of Science Fairs

Despite the abovementioned positive characterisation of Science Fairs, Bencze and Bowen (2009a) and Czerniak and Lumpe (1996) argued that the literature has also been somewhat critical about the Fairs in terms of incorporating them in students' learning. The criticisms have been directed, for instance, to administrative burdens placed on teachers, as well as burdens on parents in relation to material support (Craven & Hogan, 2008). Furthermore, lack of fairness in the Fairs, as evident in disparities regarding financial resources (Bunderson & Anderson, 1996) and resource facilities (Bencze, Bowen, & Arsenault, 2008; Craven & Hogan, 2008) available to the participating students, had been raised as well. On that note, some teachers even argue that the Fairs are merely a field of competition between either parents or teachers (Rohde, 2004). Grote (1995, p. 276) also contested that the Fairs are marred with “unproductive” judging of the projects, which is associated with two other contested aspects raised by Bencze and Bowen (2009a) – the Fairs’ competitive nature (also supported by Bunderson & Anderson, 1996; McBurney, 1978) and biases towards certain types of investigations.

Apart from the above reviews regarding Science Fairs, the key educational goals attributed to the Fairs – attitudes, skills, and knowledge and understanding (Woolnough, 1994) – have also been questioned (Bunderson & Anderson, 1996; Robinson, 2003).

Attitudes. According to Wilson, Cordry, and Uline (2004), there is little confirmation from students that their participation in Science Fairs elicits positive attitudes towards science. Indeed, recently, Craven and Hogan (2008) argued that there is a need for reassessment of Science Fairs. Craven and Hogan argument was based on the opinion that, the final projects at school Science Fairs are based on flawed assumption that they reflect students’ interest. Furthermore, the Fairs’ compulsory nature casts more doubts in terms of their ability to induce motivation in students to embark in scientific projects (Abernathy & Vineyard, 2001; Bencze & Bowen, 2009a; Bunderson & Anderson, 1996). Surprisingly, for the students who are motivated, it is argued that their motivation is merely the outcome of science aptitude and positive attitudes rooted from previous experiences with the Fairs they won (Robinson, 2003; Wilson, Cordry, & Uline, 2004). As we shall discover later, Kevin Rochford’s studies in South Africa painted a different picture regarding the abovementioned negative opinions.

Skills and knowledge and understanding. Apart from the attitudes, the possible development of students’ skills and competences form another contested outcome of Science Fairs in positional papers (e.g., Craven & Hogan, 2008; McBurney, 1978) rather than in research papers in which arguments are constructed from studies conducted with participants – a gap in the literature that the current study should fill. For instance, opinions by McBurney (1978) showed that certain science projects in Sciences Fairs might “not enhance student understanding of what science is” (p. 420).

The same opinion is embraced today. Craven and Hogan (2008) assert that Science Fairs are based on flawed assumptions that they accurately reflect what science is all about. Bencze and Bowen (2009b) also argued from their observations that students' works remained templates of stereotypical norms of *practices* marked by the highly criticised classical "scientific method". Chiappetta and Adams (2004) had revealed dangers of such practices: "We have observed science fair projects in which students do an exemplary job of presenting the scientific process or 'scientific method' that was used, but cannot explain the phenomenon under investigation" (p. 50). Craven and Hogan (2008) also presented their argument on the scientific method within Science Fairs context. They argued that students' tendency to follow a "scientific method" in Science Fairs that starts with a prediction framed on a particular phenomenon and then ends with a conclusion that supports the prediction casts doubt on whether the "young scientists" in the Fairs actually understand the process of science used in their respective science projects.

Science Fair projects

Despite the abovementioned critique of Science Fairs, educators have for a long time shown steadfast loyalty in investigational science activities associated with Science Fairs themselves, Science Talent Searches, Science Expositions, or Science Olympiads. Woolnough (1994, p. 47) termed these activities "student research projects" (also known as scientific investigations, projects or independent science research projects). For Grote (1995), an activity qualifies as a research project if an individual or a team of students under a supervision of a teacher or mentor, engage in background research, design experiments, and communicate their science information resulting from the experiments.

Research projects may also be directly linked to a school science curriculum, which explains why they "have become increasingly popular within the school curriculum itself in recent years" (Tytler & Swatton, 1992, p. 395), especially in the Life Sciences. They have become an integral part of a significant development in the realm of international science education, probably because of their ability to develop in students "an appreciation for nature and relevance of science in daily life" (Balas, 1998, para. 5). Indeed, one of the leading proponents of student research projects in science education, Brian Woolnough, and other researchers in science education argued about the rationale for the tradition of student research work in school science. Firstly, Woolnough (1994, p. 53) pointed out the following key attributes of these "long and noble" (p. 49) science activities:

- They are based on a problem or a question of interest to the student, which is associated with a scientific phenomenon. However, teachers often make suggestions. Furthermore, apart from support from teachers, students may be provided with additional support at home in the form of advice, resources, stimulus or judgement.
- Inspiration to embark on these endeavours comes from students themselves. Hence, the students have a considerable amount of autonomy and independence. Though these projects are "owned" by the students, teachers become facilitators or mentors that provide assistance and/or suggestions in terms of the background information and research question(s).
- They are open–ended (i.e., with no single correct answer) and occur over an extended period of time (i.e., usually more than a week), so that reflection, discussion and modification of the research design can take place in out–of–school time.
- The problem inherent in these activities provides an element of personal challenge to the young researchers.
- Students may embark on these endeavours as a team or as individuals.
- Normally, the students utilise out–of–school resources; that is, from home or the school "junk box" for their projects.
- The outcome may be a project report and/or an artefact exhibited at, for example, a Science Fair or Science Expo for the judges and the public. The students often obtain a successful and satisfying outcome.
- They build on the students' existing knowledge and additional information gathered through personal research.

There are several reasons why different proponents and researchers of the school student projects hailed them as the noble enterprise. According to Taber (2007), students' proclivity to make observations and ask question is rooted in curiosity. Young, Jr. (2000) argued that student projects nurture this natural curiosity. Woolnough (1994) found that science teachers who had experienced learning through projects believed that students enjoy them and learn science from them, and find them highly motivating. Teachers consulted by Grote (1995) also believed that in Science Fairs, student projects might "stimulate [students'] interest and enthusiasm about science" (p. 276). Statter and Tamir (1998) summarised – based on the evidence obtained from parents, coaches and *teachers* – that individual research projects could "strengthen self–confidence, initiative, responsibility, and independence [of school students learning Life Sciences]" (p. 220). Barak (2004) also argued that introduction of projects at school may uplift students' self–image because the students may employ high technolgy resources and utilise tools and procedures of engineers. As referred to earlier, another aspect related to attitudes is initiative, and school projects are synonymous with students' initiatives (Statter & Tamir, 1998). This provide an insight as to why educationalists thought school projects formed the basis for psychological theories of how children should learn (Woolnough, 1994). According to Woolnough (1994), such theories were embedded in the progressive movement, which sought to base the curriculum around the interests of the young students as aiming to autonomous behaviour (Tytler, 1992). Industrialists are of the same opinion that the projects are valuable in terms of developing the autonomous person (Woolnough, 1994) – the person who is not only creative and innovative but a multi–skilled team player. These arguments clearly justify the claim by Abernathy and Vineyard (2001), and Wilson, Cordry, and Uline (2004) that school student projects increase positive attitudes toward science.

As stated elsewhere (p. 28), apart from positive attitudes toward science, there are more general educational outcomes that are equally valuable for students, namely, skills (they are in tandem with scientific method [Watson & James, 2004]), and knowledge and understanding. These educational outcomes have also been highlighted in the National Curriculum Statement (Chapter 1, pp. 13-14).

Abernathy and Vineyard (2001) reported on student projects in relation to these educational outcomes. They argued that, in addition to interest, the projects have been acknowledged as a way for students to develop further science content knowledge and process skills. Development of science content is expected because the pursuit and engagement of scientific methods and procedures while students conduct experiments for Science Fair projects might help them to understand scientific concepts (Bellipanni & Lilly, 1999). So (2003) pointed out that, when students learn through science projects, their understanding of scientific concepts is synonymous with their performance of scientific skills. In such a context provided by projects or activity–based learning, Life Sciences students in particular may also develop both personal and interpersonal skills (Statter & Tamir, 1998). This is important for students' future careers. Indeed, Woolnough (1994) argued that industrialists found research investigations valuable in terms of developing the autonomous person with problem–solving skills, communication and entrepreneurial skills that were fundamental to the workplace. Furthermore, Abernathy and Vineyard (2001) stated that participants of the Westinghouse Talent Search in the 1980s frequently pursued careers in the sciences in later years. Moreover, many adults subsequently working in the sciences indicated that Science Fair experiences had been the basis for their career choice.

Regardless of their positive contribution to science education in practice, Barak (2004) warned that school projects might not guarantee better learning. Barak (2004) himself and Bishop (2000) provided insights on why projects may not guarantee positive outcomes in school science. Firstly, students may not possess factors that affect their creativity in problem solving such as, for instance, their ability to follow thoroughly through the research stages. Secondly, the students may lack experience regarding autonomous learning.

Creativity in problem solving and autonomous learning, albeit they pose challenges in students' learning, are very much part of science curriculum in South Africa. They are instrumental in the development of skills and knowledge. Indeed, developments in the Natural Sciences, which are stipulated in the teacher's guide for the development of learning programmes (DoE, 2003d), emphasised the need for students to acquire, develop and demonstrate scientific skills in an environment that support not only responsibility and growing confidence but creativity as well. The focus should also be on the development and application of scientific knowledge and understanding that could be utilised in, for instance, economic activity and self–expression and as the basis for further studies in science at tertiary level (DoE, 2003d). These educational outcomes are also mandatory for Expo participants in South Africa (*ESKOM Cape Town Expo for Young Scientists*, 2007). It is imperative, therefore, that I also review literature and research on Expos in tandem with the South African science curricula.

Science Expositions: The South African context

A description of Expos within the South African context had been presented in Chapter 1 (p. 17). Science Expos in South Africa (i.e., ESKOM Expo for Young Scientists) were established in 1980, and they were meant to address challenges related to Science, Technology, Engineering and Mathematical skills, which are still facing the country today (ITWeb Informatica, n.d.). They are, therefore, the only events that make provision for different scientific disciplines (Alant, 2006; Ramsuran, 2009). Furthermore, Expos are part of extra–curricular science, in which school students exhibit their science projects for judging and to fellow participants and the public (Figure 1.1, p. 4). The students who participate strive for educational achievement with their projects rather than the prizes and prestige that go with the projects (*Cape Town Expo for Young Scientists*, *n.d.a*), especially for “the economically well established English–speaking EXPO students” (Stewart, Qanya, & Rochford, 1999, p. 146). Indeed, in *What is a science Exposition?* (n.d.a), it is claimed that Expos are the non–competition type of extra–curricular science activities (i.e., divorced from contest between students or schools). The claim is due to the participants’ exhibitions – which encompass, *inter alia*, a scientific project report, a poster, and in some cases a model – being solely judged according to the rating criteria. The criteria itself incorporate, for instance, creativity, innovation and the scientific method (*ESKOM Cape Town Expo for Young Scientists*, 2007). Similar to Science Fairs, these activities may be conducted at regional level and beyond (Alant, 2006; Molefe, 2007, 2008).

According to Exposition (2008), “Expositions grew out of the traditional medieval cloth fairs” (para. 1). Indeed, Expo for Young Scientists is also defined as a Science Fair (Alant, 2006; *Cape Town Expo for Young Scientists*, *n.d.a*). After all, Expos show distinctive characteristic that parallel those of Science Fairs, which offer all–round education experience that encompasses autonomous learning, and address students’ development of attitudes, skills, and knowledge and understanding (p. 29). According to *Cape Town Expo for Young Scientists* (*n.d.b*), in “Why would I want to participate in EXPO?”, the characteristics include:

- Science Exposition’s ability to help to stimulate an interest in Science and Technology in, for instance, school students. Hence, Expos help to deliver human resources with an innovative, problem solving attitude and critical skills to the economy of the country.
- By conducting research related to Expos, school students are provided opportunities to experience scientific processes: They develop scientific skills associated with observing and comparing, measuring, gathering information, representing information graphically, formulating hypothesis, constructing models (in some cases), and reach conclusions.
- The students may also develop a problem solving and critical thinking approach when they engage in the scientific enterprise, and start to think and do things like scientists do.
- The students are provided with opportunity to experience autonomous learning, in

which they also build their self–confidence.

- By participating in Expos, students automatically become ambassadors of their schools. Such an opportunity can extend beyond the regions and even the country they represent (i.e., and there is always an opportunity to represent the country in international science competitions). The students may then meet like peers from other cultures and get into contact with professional scientists.

The above characteristics of Expos corroborate earlier argument that Expos share the same principles with the South African science curricula (p. 34). Indeed, research studies related to Expos, albeit limited, have been conducted in South Africa, and they revealed a harmonious interplay between Expos and the curricula. For instance, process skills are acknowledged in science education and in the South African Life Sciences curriculum (Binadja, 1992; de Jager & Ferreira, 2003; DoE, 2003b; Gott & Duggan, 1995; Harlen, 1999). De Jager and Ferreira (2003) believe that the "project method" contribute specifically to the development of the process skills. Rochford (2007) found that Expos actually provide opportunities for students to acquire (and develop) "skills and abilities that are transferable to other career and life situations" (p. 178). Such skills and abilities, drawing from DoE (2003b), and the *Cape Town Expo for Young Scientists* (*n.d.b*) listed characteristics of Expos, may encompass development of students' ability to (a) identify and solve problems and make decisions using critical thinking; (b) collect, analyse, organise and critically evaluate information; (c) communicate effectively using visual, symbolic and/or language skills in various modes; (d) explore education, career and entrepreneurial opportunities which, according to Ramsuran (2009), are embedded in the field of Science and Technology.

Furthermore, in the field of science (i.e., Life Sciences), it is important that students do not merely understand skills and processes, but also understand scientific concepts and their application in society (DoE, 2003b). By virtue of offering participants further opportunities to experience science, to add to their knowledge and to broaden their scientific horizons (Alant, 2006; ITWeb Informatica, n.d.), Expos provide a context for the acquisition of both *science process skills* and scientific knowledge simultaneously (Molefe, 2007, 2008). This context offered by the Expos further explains why, by unearthing the science talent and potential of students from disadvantaged schools, the South Africa Department of Science and Technology intends to use Expos as a "vehicle of scientific and technological empowerment" (Alant, 2006, p. 177). This was evident in the Pretoria–based ESKOM Expo address by the former Minister of Science and Technology, Mr. Mosibudi Mangena, on the day that marked the Expos 25th birthday (Department of Science and Technology, 2005):

> The importance of the expo [sic] should be understood against the backdrop of technological change and globalisation of the economy. The Expo for Young Scientists provides learners with an opportunity to turn their dreams into tangible products. In other words, it enables them to sharpen their innovative skills. And in doing this, it equips them with *the requisite knowledge* and *skills* to participate meaningfully in a knowledge-driven economy (emphases added). (para. 4)

Science students are also expected to show positive attitudes towards learning (DoE, 2003b). Expos, especially in the Western Cape, have long addressed students' affective domain by providing them with "the opportunity to explore aspects of science and technology that were of personal interest to them as individuals" (Rochford, 2007, p. 185). Hence, Expos have ability to induce feelings and experiences related to the words "interest", "inspired", "ambitious", "challenged", and "fascinated" (Rochford, 1998, p. 342; Rochford, 2007, p. 185). These feelings and experiences might be related to Expos' ability to provide students with opportunities to "meet other people", "do something new for the community", design and conduct own projects, and so on (Stewart, Qanya, & Rochford, 1999, p. 145).

It is reasonable, therefore, that teachers utilise Expos as an incentive that may be used with the more capable, science–oriented students to unearth talent (*What is a science Exposition?* n.d.). It also make sense that members of the participants' families often become involved (i.e., with expertise, resources, transport, etc.), and in the process are themselves exposed to Science and Technology development within the home (see "Expo for Young Scientists," 2010). Expos thus provide a stimulating context for *science* education that can make the learning more challenging, fascinating, motivating, and powerful (Rochford, 1998).

Regardless of their evident contribution to science education practice, Expos in South Africa, like Science Fairs globally, have not escaped critique, however minimal. Alant (2006), basing her arguments on the experiences of one Expo entrant from one under–resourced school (i.e., disadvantaged), who successfully participated in the 2000 ESKOM Expo, emphasised that Expos are valuable tools that broaden students' scope of knowledge in science and technology. However, she indicated that the institution of Expos "is still not sufficiently flexible [i.e., not accommodating for students from under–resourced schools], both at a conceptual and an organizational level" (p. 177). For that reason, she considered its principles for scientific and technological empowerment for the disadvantaged students untenable. She summarised that ESKOM Expo is nothing but an exclusive institution (i.e., benefits students from well–resourced schools [i.e., advantaged]). Indeed, Priscilla Moodlley, national manager of the ESKOM Expo for Young Scientists, agreed that the South African Expos are confronted with challenges in relation to the inclusion of students from under–resourced schools (ITWeb Informatica, n.d.): "We find that disadvantaged learners often have creative ideas but lack resources" (Looking forward section, para. 1). Ramsuran (2009) concurred with Moodley's views. She argued that capacity, training and resources have been the key problematic factors in Expos. She added: "[Expo at national level] can accommodate only a certain number of projects" (findings section), which are produced by mostly students who have access to resources (from their resourced schools), and also have, for instance, conceptual prowess in Expos.

In conclusion, the ideas of incorporating Science Expositions and Science Fairs in students' learning have been met with skepticism, and Grote (1995) believed that there has been little progress in terms of positive changes, especially with Science Fairs. However, they are acknowledged in science education (Rochford, 1998, 2007; Tytler, 1992). Indeed, Woolnough (1989) and Grote (1995) acknowledged Science Fairs as valuable in science learning by school students. Woolnough (1989) elaborated that the value and stimulus that can come from "project weeks and science fairs [or Expos] should not be underestimated, for here the scientific activity really can develop naturally without the artificial constraints necessarily imposed in normal lessons" (p. 131). Czerniak and Lumpe (1996) provided a perfect summary of the significance of Science Fairs (also apply to Expos), which was based on the views of different stakeholders:

> Science teachers, science teacher educators, and members of organizations that sponsor science fairs, propose that participation in science fairs helps students to develop *basic skills*, *problem solving skills, positive attitudes, knowledge* necessary in a changing society, and *personal interests* related to science (emphases added). (p. 360)

Therefore, one can deduce from these debates that despite some lack of consensus and/or reservations about the value of the Expos and the Fairs in terms of, *inter alia*, the purpose of doing a research project, the quality of judging, cash and scholarship awards (mainly directed to Science Fairs), and disparities in relation to resources and facilitation of the students' research projects (applicable to both the Expos and the Fairs), they are still being acknowledged as useful. They provide a context for learning science in which students have opportunity to: (a) pursue their interests, concerns, and talents beyond the classroom; (b) examine practical problems with demonstrable activities that link other facets of the curriculum with science; and (c) reflect and make sense of their outright educational experience (Balas, 1998).

Summary

In Part 1, an overview has been presented of the research findings into the advocacy for students to achieve skills competence through learning science. Furthermore, an overview of the different potential roles of extra–curricula science activities in the curriculum and the teaching and learning of science and their linkages to the South African curricula have also been presented. These issues and their implications for the present study may be summarised as follows:

- The radical changes experienced in industrialised countries during the last decade have been marked by proposals around "the crucial need for creativity and innovation to be able to use the new opportunities and to solve the many serious problems that Society is facing today" (Vidal, 2007, p. 1). At the forefront in the quest to "reshaping" the society are new information, communication and biological technologies. Consequently, radical changes in curriculum frameworks in countries such as South Africa are challenging teachers to make school–based learning produce students with skills and knowledge for lifelong learning. In order to achieve this, there are key issues that need to be considered. Teachers need to provide students with an environment conducive to the development of competences in scientific skills, such as process skills that form the basis for scientific inquiry skills, critical thinking skills and problem–solving skills. Such an environment should also challenge students to construct and apply Life Sciences knowledge, and cater for the understanding that goes beyond the classroom.
- Scientific investigations in the form of project work have been acknowledged as a possibly fruitful approach for South African students to achieve meaningful learning in the Life Sciences. Research studies and opinions from literature show that these investigations are more effective if they are conducted in contexts that embrace relevance to students' interests and concerns. Such contexts are believed to have a considerable success rate as they also encompass students' positive attitudes. Moreover, they provide opportunity for autonomous learning and opportunity for students to: identify a problem; seek information from books and resource people; generate products, questionnaires, collections of data and

collections of materials from nature or industry; and create testable questions, fair tests and reports explaining their conclusions (DoE, 2003d; *ESKOM Cape Town Expo for Young Scientists*, 2007). Science Fairs and Science Expos provide these contexts, and therefore should be encouraged in schools. However, teachers should be aware that projects in these contexts embody different types of scientific investigations. Consequently, they should avoid a trap of regarding investigations as merely experiment–based as illustrated in Grote's (1995) definition of student projects.

PART 2: THE ROLE OF SCIENCE PROCESS SKILLS IN SCIENCE LEARNING

Central to students learning through investigative activities (e.g., student projects) is the students' demonstration of their understanding of scientific concepts and the processes of science. In South Africa, the process skills ordinary students learnt in the Natural Sciences need further development. It is asserted in the Life Sciences that they are best developed within the context of an expanding framework of knowledge. This suggests two main aspects related to students learning within such a context. Firstly, the role of process and content in science, and the debates around the process and content approach, as well as the assessment frameworks for process skills. Secondly, the appropriate means for developing process skills of students.

Hence, it was important that a review be made of literature and research to explore the process approach, the relationship between content and process, science process skills, as well as research findings into the teaching and assessment of science process skills in school classrooms. Furthermore, it was important that I also make reference to methods and means of enacting process skills in science teaching.

The literature related to science teaching and learning shows that there have been debates about the school science skills, processes, and content, and/or their associated development and assessment (e.g., Arena, 1996; Chiappetta & Adams, 2004; de Jager & Ferreira, 2003; Fairbrother, 1989; Germann & Aram, 1996; Harlen, 1996; Huppert, Lomask, & Lazarowitz, 2002; Millar, 1989; Millar & Driver, 1987; So, 2003; Soyibo, 1998; Soyibo & Beaumont–Walters, 2001; Wellington, 1989; etc.). The debates bring us to the following questions: Is meaningful learning embedded in content–based approach than process–based approach or vice–versa? Does the development of process skills within the context of an expanding framework of knowledge provide the ideal balance between process, content, and context?

"Process", "content" or both?

Some debates on the issue of the role of "content" versus "process" in school science had been raised by researchers such as Chiappetta and Adams (2004) in America, So (2003) in China, Millar & Driver (1987) in the United Kingdom and, to a lesser extent, by de Jager and Ferreira (2003) in South Africa. Wellington (1989), in particular, produced more elaborate analyses of content and process from the perspectives of different scholars. His analyses supplemented Millar and Driver's (1987) critical analyses of these two issues.

The debates on processes we use (e.g., in Millar & Driver, 1987; Millar, 1997; Wellington, 1989) have been based on whether they are scientific or innate. Indeed, Harlen (1999) pointed out that scientific process skills qualify as scientific if they are applied in the context of science. In the current study, processes students use were applied in science context. They thus refer to an aggregate of the skills and procedures that are practiced and utilised in scientific investigations (Millar & Driver, 1987; So, 2003). In Life Sciences, in particular, processes may incorporate ways of thinking, solving problems and using thoughts, especially when making, manufacturing or achieving something in Life Sciences (de Jager & Ferreira, 2003). They are, therefore, synonymous with inquiry and discovery learning (Chiappetta & Adams, 2004). In fact, So (2003) argued that the scientific way of working might have emanated from the following central processes, each of which is characterised by essential practical and intellectual skills: hypothesising, planning science investigation, conducting science investigation, recording, interpreting science information, and communicating science information. There are also other activities synonymous with processes that have been reported, such as observing, classifying, inferring (Millar, 1989), defining operationally, experimenting (Arena, 1996), measuring, tabulating and making graphs, raising questions, using secondary sources of information and manipulating of equipment (So, 2003).

On the other hand, content has been defined as that body of knowledge that results from scientific inquiry (Chapman, 2001; Chiappetta, 1997; Chiappetta & Adams, 2004; Rillero, 1998). Such a body of knowledge may encompass "the facts, concepts, laws, principles, and theories used to explain objects and events associated with natural phenomena" (Chiappetta & Adams, 2004, p. 47). It should be noted that traditionally, science content had been so important that it was synonymous with science curriculum (Kirkham, 1989). Acquisition of scientific knowledge was embraced as an educational objective; therefore, a shift from process to content was inevitable (Jenkins, 1989).

As stated previously (p. 40), both content and processes had however been subjected to critical analyses. There has been a conventional view that compared to the apparently activity–oriented and "progressive" pedagogy–bound "science process", content is correlated with a passive view of learning in which teachers are "transmitters" of knowledge to students who are merely "absorbers" of it (Millar & Driver, 1987, p. 37). This conventional view of content clearly set a stage for strong arguments on the legitimacy of "content–led approach" in science education (Simpson, cited in Wellington, 1989, p. 8; Millar, 1997), with the subsequent call for process approach to science curriculum (Millar & Driver, 1987). In fact, in general, when science educators reflect on science, curriculum, and students learning, they tend to be drawn towards justifications in relation to methods of science over content (Millar & Driver, 1987). In South Africa, for instance, proponents of outcomes–based education heavily criticised the "traditional approach" towards teaching and learning (Rambuda & Fraser, 2004). Indeed, Wellington (1989) provided insights regarding the criticisms of content–led approach, and the defense of process–led science curriculum. Wellington (1989) elaborated that proponents of the latter argued that if science catered for all abilities, then process–based curricula were necessary. Such curricula were perceived to have the ability to enable students develop skills that are applicable in novel contexts. Moreover, the proponents claimed that scientific facts are not absolute. They also reasoned that with the information explosion, teaching facts remained debatable.

Regardless of the justifications for science processes, the validity of the process approach to science education had been questioned in the literature (e.g., Chapter 1, p. 15; Millar, 1989; Millar & Driver, 1987; Wellington, 1989). In his single and co–authored publications, Millar had eloquently argued that the process approach was questionable. For instance, Millar and Driver (1987) and Millar (1997) claimed that despite their "scientific" tag, processes were merely characteristics of many human endeavours. In his elaboration, Millar (1989, 1997) asserted and demonstrated that it was incorrect to portray the method of science as a set of discrete processes. He went a further to say that most of the so–called processes of science are general cognitive skills which we routinely exercise throughout our lives and, hence, cannot and/or need not be indoctrinated (because what constitute students' learning progression in processes is unknown). Millar (1989) argued that the science processes–oriented approach is an inductivist view of the scientific method that has been questioned in the literature. Furthermore, "in educational context, the *discovery learning* approach, which is modelled on inductive view of science" (emphasis in the original) has also been discredited in the literature (Millar, 1989, p. 50). Millar (1989) presented what could possibly be "an alternative" – the hypothetico–deductive view of science – that he, however refuted on the basis that it has also been flawed. Consequently, he concluded that there was no common view among historians, philosophers and science sociologists on whether science has a method. Indeed, Millar and Driver (1987) concurred that because scientists solve problems in different ways, there is no definite method of science. For Millar, much of scientists' knowledge of the method(s) they follow was tacit. Recently, Watson and James (2004) agreed with Millar and Driver's (1987) perception of the scientific method. They argued that, although the scientific method is used as a structure of most Science Fair projects, students beyond middle school should not use it as a structured approach, in which a stepwise process associated with the scientific method, is used to solve scientific problems.

These views on content and processes had provided a springboard for different authors to justify the need for balanced science curricula such as, for example, the one that embraces development of scientific skills within the context of an expanding framework of knowledge (DoE, 2003b). Indeed, Wellington (1989, p. 148) argued: "We need a *content framework* that will co–ordinate with the *process framework* and over which we can lay the *context framework*" (Figure 2.1; emphases added). For Harlen (1999) process skills have to be utilised in relation to some scientific content, and that the context of a learning activity influences performance (although Harlen points out that context is a matter of contention when considering issues of cognitive demand). Hence, in the light of the growing emphasis for balanced science curricula, it could be concluded that "*process* in science has no meaning independently of its *content* and *context*" (Wellington, 1989, p. 1; emphases in the original), especially now that science cannot be characterised as either content nor process alone (Harlen, 1996). After all, for students learning through science projects, it is important that process skills are practiced and utilised in scientific contents, and that relevant knowledge and understanding are gained through the use of such skills (So, 2003). Moreover, the scientific content provides a 'launch pad' and guidance for scientists in their quest to search for patterns and regularities in phenomena investigated through utilisation of science processes (Germann & Aram, 1996). Hence, both processes and knowledge are essential for construction of new understandings of those patterns, relationships and basic rules, and new meanings that are open to revision and reinterpretation with time (Germann & Aram, 1996). Chiappetta and Adams (2004) added that an approach that is solely embedded in process is divorced of cognitive research and untenable within the realm of school science teaching and learning because “students learn skills that can be generalized most effectively within the context of specific content” (p. 50).

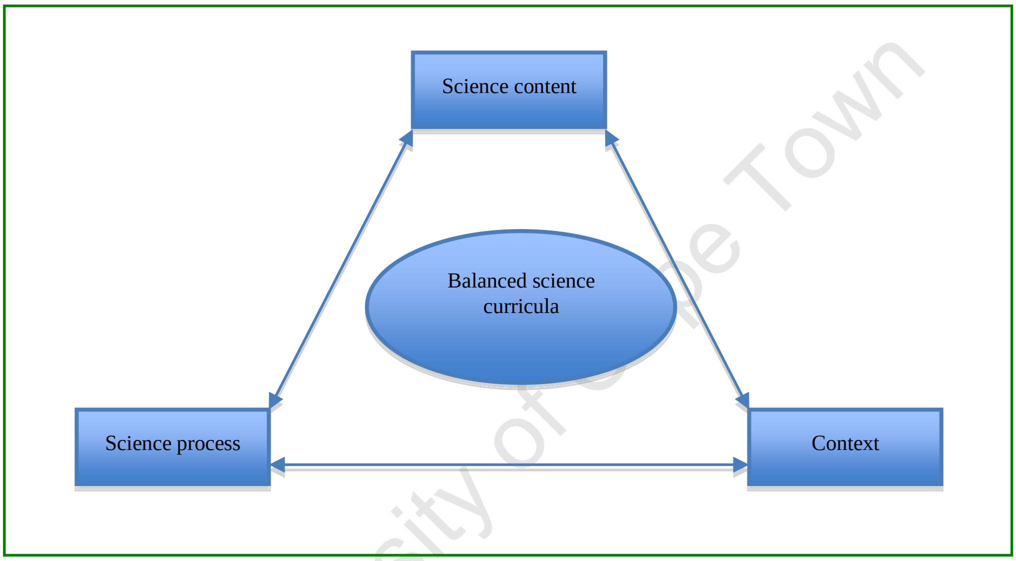

Figure 2.1. Process, content and context: Three dimensions in dynamic equilibrium in science curricula. From Wellington (1989)

Although the process with content approach have been proposed in science curricula (e.g., the South African Life Sciences emphasis on the development of scientific skills within the context of an expanding framework of knowledge [DoE, 2003b]), Chiappetta and Adams (2004) warned that the approach may not lead to the intended goals. They went further to say that even in Science Fairs or Expos students may do an exemplary job of conducting their investigations within scientific parameters, but then fail to explain the phenomenon under investigation. If a balanced science curriculum has its own flaws as well, then the need to update science programmes in school science is required more than before. Such updates should encompass increased practice in processes and skills to ensure that students are proficient in explaining phenomenon under investigation. De Jager and Ferreira (2003), and Germann and Aram (1996) suggested that, in Life Sciences, such practice should involve students exercising their process skill competences to acquire and apply information to real life situations.

Process skills/Science process skills

The rationale for science process skills in our contemporary society has been based on an exponential increase of information (Arena, 1996; Harlen & James, 1997), which has been associated with rapid advancement in knowledge and technology over the decades (Bilgin, 2006). As a result, learning that is solely based on pre–packaged knowledge has become increasingly difficult and impractical (Bilgin, 2006; Arena, 1996). Arena went further to say that the implication is science education practice should now include supplying a *context* for any active cognitive engagement that involves the processes of problem identification, experimentation, data interpretation, hypothesising and testing. The shifts away from the acquisition of mere factual knowledge to the attainment of broader objectives such as conceptual understanding, skills, processes, applications, and communication has thus become an essential part of educational policy documents. Modern science education should also emphasise developing a proficiency in *skills* and *processes* such as those associated with obtaining data and information; evaluating it and communicating the most important aspects (Bilgin, 2006; Arena, 1996). After all, "people are expected to use and apply them in all aspects of their regular life" (Huppert, Lomask, & Lazarowitz, 2002, p. 807).

Skills and processes might have shared equal spotlight in recent developments in science education, but they are perceived as not synonymous (de Jager & Ferreira, 2003). The definition of processes has already been stated (p. 41). De Jager and Ferreira (2003) consider "a skill as a specific activity that a learner learns to do…[and that] it can be a visible action…[and] it can be assessed" (p. 188). They went further to present the basis of science process skills. According to them, the task of distinguishing between processes and skills has not been easy. As a result, they believed that scholars often combined the two words and refer to them as "process skills".

Harlen (1999), like Millar and Driver's (1987) perception of processes, argued that science process skills were merely characteristics of many human endeavours and, as such, could qualify for the scientific "tag" if they were applied in the context of science. Consequently, within the context of science, process skills can be defined as activities that scientists implement when they engage in a study or investigate a problem, an issue or a question (Rambuda & Fraser, 2004). They are intellectual tools and procedures of scientific investigation (Bilgin, 2006; Ogunniyi & Mikalsen, 2004). In simplified terms, process skills refer to essential proficiency in doing science/investigative activity. For instance, *observing* biological phenomena is fundamental to carrying out Expo projects related to Life Sciences. Accordingly, when students are learning science within the context of, for instance, process and content approach, they are expected to accustom themselves with a number of these skills (Chiappetta & Adams, 2004; Rambuda & Fraser, 2004; So, 2003; Millar & Driver, 1987).

In relation to the role of science process skills in students' acquisition of science–based learning outcomes, Ogunniyi and Mikalsen (2004) contend that "process skills entail the use of concepts, and the manipulation of concepts involves process skills" (p. 152). Bilgin (2006) also points out that through the development of science process skills students might be able to interpret knowledge. Harlen (1999) elaborates that:

> if these skills are not well developed and, for example, relevant evidence is not collected, or conclusions are based selectively on those findings which confirm initial preconceptions and ignore contrary evidence, then the emerging concepts will not help understanding of the world around. (p. 130)

As a result, science process skills are acknowledged as a key to the generation of content and concepts (Rambuda & Fraser, 2004). The Martin, Sexton, Wagner, and Gerlovich (1994) considered them (i.e., process skills) as the platform for thinking, measuring, solving problems, and using thoughts. Indeed, the South African curriculum shows that when students use process skills to investigate, reflect, analyse, synthesise and communicate, they develop proficiency in thinking objectively and using different forms of reasoning (DoE, 2002). Science process skills are therefore cornerstones in meaningful and lifelong learning because individuals have to be proficient in seeking information, interpreting it and judging evidence under various contexts (Bilgin, 2006). Thus "teachers and learners can apply science process skills while developing teaching and learning inquiry competences" (Rambuda & Fraser, 2004, p. 10), and utilise the terms *the scientific method*, *scientific thinking*, and *critical thinking* to describe them (i.e., science process skills) (Padilla, 1990). Table 2.1 illustrates how the scientific method melds with science process skills.

Table 2.1

Melding scientific method with science process skills (Watson & James, 2004)

The scientific method	**Science process skills**
Problem/research question	Observing, Communicating
Research/Background knowledge	Communicating, analyzing investigations
Hypothesis	Predicting, Communicating, Identifying variables, Constructing hypothesis, Designing investigations
Experiment	Measuring, Identifying variables, Defining operationally, Communicating, Experimenting
Observation	Observing, Classifying, Communicating, Measuring
Conclusion	Inferring, Communicating, Analyzing experiments

Classification of science process skills

Brotherton and Preece (1995) and Padilla (1990) presented the hierarchical structure of process skills that could be valuable in developing inquiry competences in teaching and learning. According to them, these skills could be classified as either basic science process skills or integrated science process skills. Basic science process skills, which were identified by Beaumont–Walters and Soyibo (2001), Chiappetta (1997), Colvill and Pattie (2002), de Jager and Ferreira (2003), and Rambuda and Fraser (2004), included *observing*, *measuring* and *classifying*. *Communicating* (de Jager & Ferreira, 2003; Rambuda & Fraser, 2004), *predicting* (Beaumont–Walters & Soyibo, 2001; Chiappetta, 1997; Colvill & Pattie, 2002; de Jager & Ferreira, 2003), *inferring* (Colvill & Pattie, 2002; de Jager & Ferreira, 2003), *using numbers* (Chiappetta, 1997), *space/time relations* (Chiappetta, 1997; Colvill & Pattie, 2002) and *recording/displaying data* also constitute the basic skills.

Rambuda and Fraser (2004) asserted that integrated science process skills are more advanced than the abovementioned skills. This implies that basic science process skills are prerequisites for the integrated science process skills (Padilla, 1990; Soyibo & Beaumont–Walters, 2001), and mastery of these skills in Life Sciences is essential to utilise integrated science process skills effectively when executing scientific investigations (de Jager & Ferreira, 2003). Indeed, Soyibo and Beaumont–

Walters (2001) argued that basic science process skills provided the basis for the fundamental intellectual hallmark in scientific inquiry. They argued further to suggest that proficiency in utilisation of basic process skills was attributed to the capability to execute empirical–inductive reasoning or Piagetian concrete operational reasoning. Rambuda and Fraser (2004) affirmed that these simpler skills apply specifically to foundational cognitive functioning, especially in the lower grades (e.g., elementary grades). They went further to suggest that these basic process skills were also prerequisites for the more advanced problem–solving skills and capacities. Hence, "they represent the foundation of scientific reasoning learners are required to master before acquiring and mastering the advanced integrated science process skills" (Soyibo & Beaumont–Walters, 2001, p. 133). Such integrated science process skills may encompass *formulating hypotheses*, *experimenting* (Beaumont–Walters & Soyibo, 2001; Chiappetta, 1997; Colvill & Pattie, 2002; de Jager & Ferreira, 2003; Rambuda & Fraser, 2004), *identifying and defining variables*, *describing relationships between variables*, *designing investigations*, *collecting and transforming data*, *constructing tables of data and graphs* (Beaumont–Walters & Soyibo, 2001; Rambuda & Fraser, 2004), *controlling and manipulating variables* (de Jager & Ferreira, 2003), *interpreting data* (Beaumont–Walters & Soyibo, 2001; Chiappetta, 1997; Colvill & Pattie, 2002; de Jager & Ferreira, 2003), *analysing investigations* (Rambuda & Fraser, 2004), *formulating models* (Chiappetta, 1997), *manipulating materials* and *drawing conclusions and generalising* (Beaumont–Walters & Soyibo, 2001).

The South African science curriculum (i.e., Natural Sciences [DoE, 2002]) prescribed eleven process skills (both basic and integrated) that need to be developed further in Life Sciences. In regard to basic process skills, Rambuda and Fraser (2004) contend that students can demonstrate and apply more than one in any single science activity. For instance, in an activity in which students investigate temperatures of different states of water in a given region, students may demonstrate and apply at least three basic skills. The students may need to *classify* ice as solid, water as liquid, and steam as gas. As *measuring* (i.e., accurate and precise measurements of water temperatures) forms the basis for accurate observations, it becomes a skill for students to carry out *quantitative observations* using standard unit equipment – thermometers. The students may eventually *record* their findings in tables using appropriate units before they could plot graphs. In regard to integrated process skills, Arena (1996) argued that publications related to process skills at secondary level showed inclination towards basic skills than these skills. It is thus imperative that I present methods and means in which simultaneous development of the basic and integrated science processes skills, as demonstrable outcomes in an appropriate context, can be achieved.

Methods and means of enacting process skills in science teaching and learning

Cultivation and enhancement of science process skills and problem–solving ability (e.g., proficiency in thinking critically, reasoning analytically and creating productively, all of which involve quantitative, communication, manual, and critical–response skills) of students have long been acknowledged as important objectives of science education (Chang & Weng, 2004). Hence, Arena's (1996) claim that the rise of science process skills to prominence was rooted in the need for skills competence in the complex world in which we live was reasonable. His argument that if science process skills are acknowledged as fundamental in science education, the examination of useful means and methods of enhancing their development attains considerable significance as well, was also reasonable. On that note, several scholars (e.g., Arena himself; Chiappetta & Adams, 2004; Flick & Lederman, 2004; Germann, 1989; Llewellyn, 2005; Phillips & Germann, 2002; Roth & Roychoudhury, 1993; Wilke & Straits, 2005) have endorsed a call for provision of opportunities by teachers for students to use and develop these skills within an investigative framework.

De Jager and Ferreira (2003) and Wilke and Straits (2005) have shown that inquiry fits in the investigative framework, especially for utilisation and development of scientific skills in Life Sciences. In fact, in South Africa, different methods of investigation that encompass a wide array of fields of inquiry are recommended in the Natural Sciences Learning Area (DoE, 2002). Inquiry has been a key component of science education since the post–Sputnik science education reform that began in the late 1950s (Chiappetta & Adams, 2004). It is "*multifaceted*, involving the *basic* and *integrated science processes* as well as the use of *critical* and *logical thinking*" skills (Phillips & Germann, 2002, p. 512; emphases added). The implication is that, inquiry may enable science students to experience the scientific method that is used as a structure of most Science Fair projects or as a component of student laboratory reports. After all, Wilke and Straits (2005) and Windschitl and Buttemer (2000) argued that inquiry has been closely linked with the scientific method. However, it should be noted that, compared to such traditional classroom–oriented step–wise scientific method, inquiry is non–linear and, as such a complex process (Krajcik *et al.*, 1998; Figure 2.2).

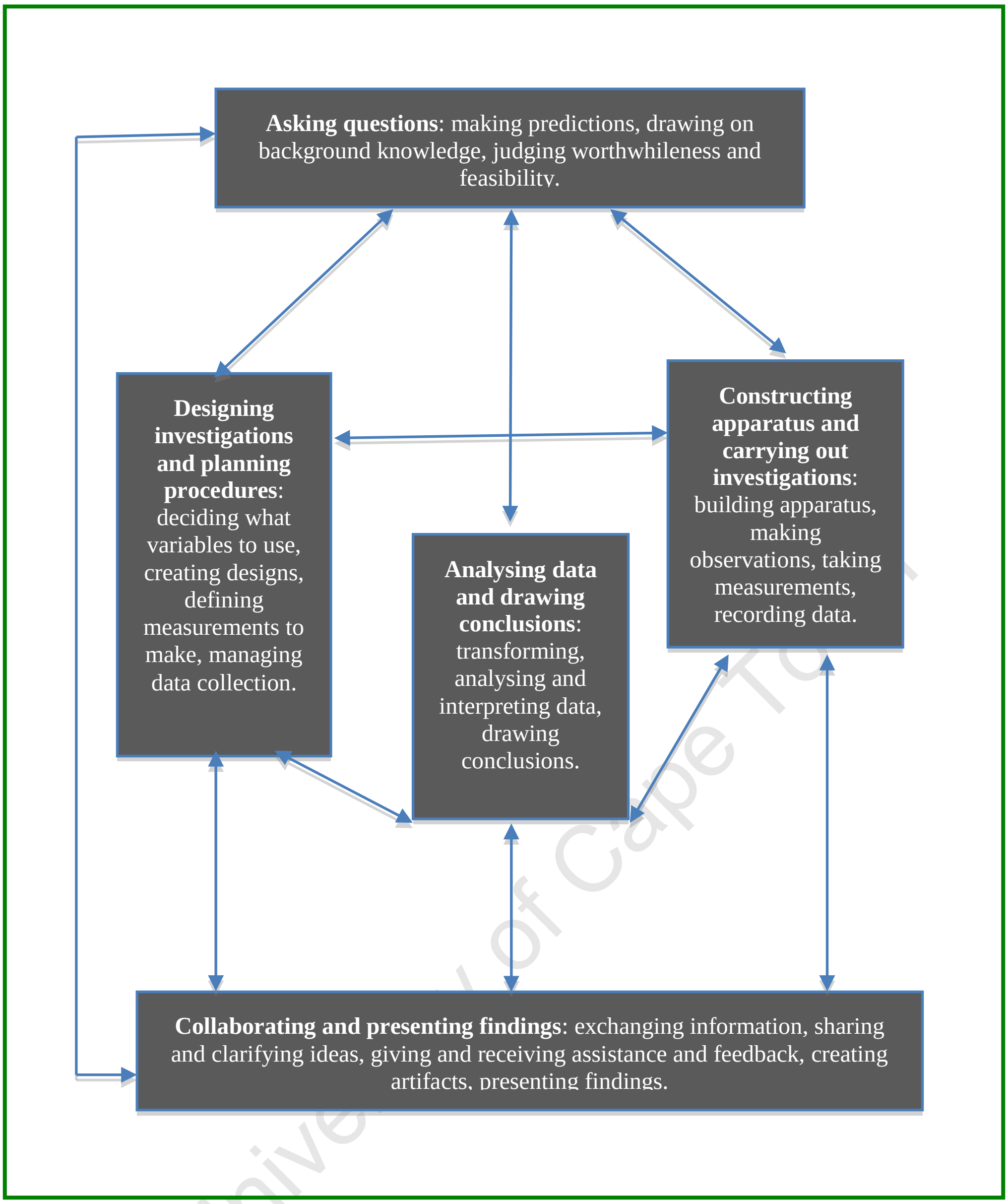

Figure 2.2. A typical inquiry process. Adapted from Krajcik *et al*. (1998)

Drawing on Krajcik *et al*. (1998), the present Expo students' research questions formulated from research related to biological phenomena may feed forward to designing, for instance, surveys or fair tests; meanwhile the students may recognise that such designs allow for the study of particular questions so that a particular design feeds back to question generation. Likewise, a fortunate stroke of serendipity related to findings may result in the modification of the original question, and preliminary data analysis may feed forward to alternative ways of collecting data that is free from biases, interests, motivations in the procedures and interpretation of the results.

Such a complex process (i.e., inquiry) may thus entail students developing, for instance, their reasoning skills, higher–level thinking, as well as science processes (Germann, Aram, Odom, & Burke, 1996). De Jager and Ferreira (2003) contend that inquiry methods incorporating, *inter alia*, "project method" actually could contribute to the development of process skills in biology in South Africa. As Llewellyn (2005) pointed out, inquiry evidently involves more than just the use of scientific skills in the classroom. Inquiry is pivotal to forming curriculum goals, designing instructional strategies and assessing learning, and to describe what scientists do (Chiappetta & Adams, 2004; Flick & Lederman, 2004). It is, therefore, science itself (Zion *et al*., 2004).

Indeed, Chiappetta and Adams (2004), Flick and Lederman (2004), and Llewellyn (2005) showed that inquiry is in relation to students' understanding of science. All these researchers share the perception that, by engaging students in inquiry, we enable them:

- to understand fundamental facts, concepts, principles, laws and theories;
- to develop scientific skills that hone the acquisition of knowledge and understanding of natural phenomena;
- to improve their proclivity to find answers to questions and to critically examine the truthfulness of statements about the natural world;
- to develop positive attitudes towards science; and
- to acquire an understanding about the nature of science.

Zion *et al*. (2004) concurred with the abovementioned researchers. They pointed out that through development of inquiry skills students were expected to attain an understanding of concepts and content, an understanding of the process of scientific inquiry and an understanding of the nature of science, as well as positive attitudes towards science. In a more recent study, Yager and Akcay's (2010) results actually showed that student utilisation and understanding of science skills and concepts in inquiry setting increased considerably in terms of creativity skills, process skills, ability to apply scientific concepts, and the development of more positive attitudes to science.

Chiappetta and Adams (2004) added that inquiry had also been utilised to "promote activity–oriented learning that reflects scientific investigation, specifically the observation, experimentation, and reasoning used by scientists" (p. 46). Chiappetta and Adams's argument actually support Zion *et al*. (2004) assertion that, in most science curricula, it was believed that learning science is meaningful if it is focused on the problem and performing the experiments, observations and calculations. Ingram, Lehman, Love, and Polacek (2004) argue that this trend in literature in which inquiry is framed as students' proficiency in performing experiments has to change. They reason that students can successfully complete a considerable portion of inquiry through contemplation and evaluation. They go further to illustrate that – for students who cannot or do not perform experiments – inquiry may be used to make sense of data or providing evidence–based interpretations of data.

Despite these rhetorical assertions about inquiry by its advocates, its role in science teaching and learning has also been under scrutiny (Germann, 1989; Holliday, 2004; Zion *et al*., 2004). Germann (1989) pointed out that directed–inquiry teaching has no significant impact on students' learning of process skills. On the other hand, Zion *et al*. (2004) examined confirmation, structured, guided and open inquiries from the literature within the context of Life Sciences/biology. They observed the following critical issues associated with inquiry:

- Citing Mendelovici, Zion *et al*. (2004) reported that teachers' perception of inquiry activities as "assurance" for textbooks, or as preparation for final exams, had lent itself to inquiries being "cookbook recipes"–oriented activities that were teacher–centred rather than student–centred (p. 729).
- From the work of Gabel, they argued that results obtained from "open types of inquiry" conducted with high school students revealed "that the students did not usually progress to higher level of process skills" (p. 729).
- According to Zion *et al*. (2004), Ogens's work revealed that students might express enjoyment as they engage in practical activities (e.g., laboratory or field activity), but that they could not necessarily acquire scientific concepts and principles and did not necessarily develop positive attitudes to science and, as such, might fail to explain phenomena under investigation.
- Drawing from the findings of Penner and Klahr, Zion *et al*. (2004) reported that students failed to conceptualise and utilise inquiry as the basis/process for suggesting and examining explanations for natural phenomena. In more simplified terms, students "failed to perceive the essence of inquiry as a process that combines an experimental and an intellectual aspect" (p. 729).
- Zion *et al*. (2004) argued further that inquiry does not provide a meaningful context in which students could emulate scientists' efforts in their quests to

construct explanations for phenomena in the “real world” (p. 729), and that the students do not understand that scientific knowledge is not absolute but its the product of a continuous process of reexaminations and updates.

- Zion *et al*. (2004) maintained that students’ experiences with regard to scientific assignments are once more imbedded in anticipated results. As a result, the students plan their experiments accordingly. For Zion *et al*. (2004), the students’ perceptions of the assignments show that their work is framed on the “engineering model” instead of a more inquiry–oriented “scientific model” (p. 729).
- Within the context of curriculum, and drawing from Chinn and Malhotra who defined the characteristics of the authentic inquiry process, Zion *et al*. (2004) point out that performing inquiry tasks “does not enable students to experience cognitive processes that characterize authentic science” (p. 729). According to Zion *et al*. (2004), this corroborates reports by Bell, Blair, Crawford, and Lederman; Germann, Haskins, and Auls; and Ogens, that teaching through inquiry has a limited influence on high school students.

Regardless of these criticisms, different scholars (e.g., Arena, 1996; Germann, 1989; Llewellyn, 2005; Roth & Roychoudhury, 1993) had argued that the open–inquiry style still remains one of the appropriate methods of enacting process skills in science learning. Arena (1996) in particular put it eloquently. He argued that, with motivation and interest driving the entire learning process, a student centred open–inquiry approach,

> appears best suited to promote the *use of process skills* in science as it provides students with the opportunity to investigate problems of particular *relevance* to them encouraging *ownership* whilst also *engaging the integrated processes* which are commonly found to be the most difficult to learn (emphases added). (p. 37)

Furthermore, there are three inquiry–based approaches to learning namely, project learning, problem–based learning, and design–based learning (Barron & Darling-Hammond, 2008). Project work/learning, in particular, has been suggested for school students (Arena, 1996; de Jager & Ferreira, 2003; Hobden, 2005; Krajcik *et al*., 1998; Molefe, 2008). After all, project work has the following significant key components described by Barron and Darling-Hammond (2008), which are essential in inquiry, and justify claim by Arena (1996) that inquiry should be in science courses: (a) centrality to the science curriculum; (b) driving questions that lead students to encounter key scientific concepts; (c) investigations that involve inquiry and development of scientific knowledge; (d) scientific processes that are driven by students, rather than their teachers/mentors; and (e) real problems that needs immediate attention in the real world (Barron & Darling-Hammond, 2008, Project-based pathways section, para. 1).

Hence, it could be concluded that despite the contestable nature of inquiry in relation to its role in learning and teaching, suitable forms of inquiry, such as project work, might provide a “loft mechanism” for honing students’ proficiency in science process skills. Apart from that, it is clear that science process skills associated with these endeavours might also be fundamental in learning and teaching, not only in various countries’ curricula but also in the South African curricula.

Overview of the context of process skills in the South African curriculum

Countries around the world, including South Africa, have engaged in curriculum development in science education characterised by a rationalisation of content and an increasing emphasis on process skills (Arena, 1996; Rambuda & Fraser, 2004). Indeed, so important are process skills that it is believed South African students will not be able to engage with the world and gain intellectual control of it through formation of concepts without these skills (DoE, 2002). De Jager and Ferreira (2003) argued that in the Life Sciences these processes are used by students to obtain factual information and, as a result, Life Sciences teaching should concentrate on them as much as the information. The reason for this is embedded in one of the purposes of outcomes–based education (OBE) – ensuring that all students are equipped with knowledge, skills, competence, and qualities essential for their success after tertiary education (Spady, 1994).

As described elsewhere (Chapter 1, p. 11), the OBE philosophy in South Africa had initially been adopted through *C2005.* The National Curriculum Statement became a tool upon which to fill gaps realised in the implementation of *C2005*. The emphasis of the philosophy has been a paradigm shift from what Rambuda and Fraser (2004, p. 10) called “the traditional product–driven approach” to the execution of a process approach and the associated development of process skills. In fact, in South Africa, the science curricula developers envisage that the teaching and learning of science is meaningful if it involves the development of a range of process skills that may be used in everyday life, in the community, and in the workplace (DoE, 2002). Science process skills are therefore building blocks for scientific literacy (Colvill & Pattie, 2002, 2003; DoE, 2002).

For teachers, science process skills are perceived by the curriculum developers as "building blocks from which suitable science tasks are constructed" (DoE, 2002, p. 13). Such constructed tasks should have investigations that involve inquiry because scientists use process skills only when they engage in investigations. Indeed, similar to the Expos, the Western Cape Department of Education (WCDE, 2002) and the South African science curricula (DoE, 2003b, 2003d) in the Learning Areas of Natural Sciences and Life Sciences put emphasis on scientific investigations/projects. These investigations provide a context for the development of educational outcomes that include process skills. It is reasonable, therefore, that without these building blocks teachers may not be able to design questions (or assessment standards) that can elicit, in students, the kind of competences required by learning outcomes stipulated in the science curricula of South Africa (DoE, 2002) (or more specifically, the Western Cape science curriculum [WCDE, 2002]). However, it should be noted that Wilke and Straits (2005) believe that if science process skills are the building blocks, then "[each one of them] must be developed before one can proceed to full scale investigations" (p. 534).

Whether scientific inquiry is utilised to teach process skills, or process skills are the means by which inquiry can be accomplished, it is evident that teachers should facilitate the process in which students learn the values and methods of science if they intent to produce future scientists. After all, the curriculum developers believe that ordinary students can best develop the ability to think objectively and use a variety of forms of reasoning while they use process skills to investigate, reflect, analyse, synthesise, and communicate in an environment that is typical of Expo competitions (DoE, 2002). For higher grades (Grades 10–12) in the field of science (e.g., Life Sciences), such environment that is typical of Expo competitions is considered ideal for the development of process skills, which allow students to develop scientific inquiry and problem–solving competences (DoE, 2003b). The environment is also considered essential for the development of skills of communication, critical thinking, and proficiency in utilisation and evaluation of evidence (Harlen, 1999; Kazeni, 2005). Indeed, the Life Sciences curriculum clearly shows that students are introduced to some of these process skills in the South African General Education and Training band but they "need further *development*. In addition [to the process skills that need further development], new skills need to be *developed*" (DoE, 2003b, p. 10; emphases added). Whatever the skills are developed, their introduction is likely to enable students to learn scientific phenomena with insight and understanding (Rambuda & Fraser, 2004).

In the light of these debates, it is apparent that process skills, therefore, play a significant role in the teaching and learning of science in South Africa. Moreover, because “a framework of process skills enables teachers to design questions which promote the kinds of thinking required by the Learning Outcomes…[it] is also valuable to teachers in assessment” (DoE, 2002, p. 13).

Assessment framework and assessment practices of process skills

> It is widely acknowledged that learning does not end with formal education but has to be continued throughout life, requiring, *inter alia*, skills of finding, evaluating and interpreting evidence. Thus the level of these skills that students have achieved as a result of their formal education is an important measure of their preparation for future life and so must be part of summative assessment. (Harlen, 1999, p. 141)

Assessment is an essential part of teaching and learning science (Llewellyn, 2005). Literature shows that the attainment of science process skills has been acknowledged as a major goal in science education (Binadja, 1992; de Jager & Ferreira, 2003; DoE, 2002, 2003c; Gott & Duggan, 1995; Harlen, 1999; Inal, 2002; Molefe, 2003, 2007, 2008; Rambuda, 2002; Rambuda & Fraser, 2004; Saat, 2004; Tytler, 1992). Consequently, it is reasonable that a framework of science process skills is valuable to teachers in assessment. With this as a point of departure, Harlen (1999) provided a comprehensive analysis of assessment of science process skills with special reference to formative, summative and national and international monitoring. Consequently, I utilised discussions in his analysis that are relevant to the current study. This will be supplemented by Millar and Driver’s (1987) and Woolnough’s (1994) views. Hence, Harlen’s (1999), Millar and Driver’s (1987) and Woolnough’s (1994) views will form the basis for my arguments in this study, especially those that fit into the South Africa context with regard to project work, such as summative assessment.

Assessment may provide us with a picture of a student’s competence at any specific moment (DoE, 2003b). Such an assessment (i.e., summative type) may involve comparing the performance of individuals with certain external standard or criteria (Harlen, 1999). Harlen illustrated that summative assessment’s principles are focused on the “review of *evidence* against criteria” (p. 135) that are curriculum–bound (emphasis in the original). The criteria (in the form of standards/levels) have a dual role. The first role is related to communicating what the students have achieved, and for educators to make judgements regarding the achievement (Fairbrother, 1989). The second one is providing some assurance that common standards had been applied (Harlen, 1999). Recently, Llewellyn (2005) introduced authentic assessment – an assessment that is related to the evaluation of Expo projects. It embraces assessment of tasks in which students are granted opportunities to demonstrate understanding of scientific concepts or skills applied in a different context, that is, outside the classroom. Similar to Radford, DeTure, and Doran (1992), Llewellyn (2005) argued that, apart from catering for assessment of content and high–order thinking skills, authentic assessment also provides opportunities for students to showcase their creativity, problem solving, and decision making competencies. Llewellyn went further to say that it involves, *inter alia*, research projects in which student's ability to apply scientific knowledge and scientific skills in research setting is judged.

Regardless of the abovementioned characteristic attributes of assessment pertinent to the current study, effective procedures for assessing processes remain challenging (Fairbrother, 1989; Harlen, 1999; Millar & Driver, 1987; Woolnough, 1994). For Harlen (1999), "the fact that process skills have to be used, and therefore, assessed, in relation to some specific content has been noted as an obstacle to arriving at a reliable assessment of skill development" (p. 141). In the current study, I will discuss this issue of content (and context), and the challenges related to validity of assessment because they are pertinent to an assessment of Expo projects.

Millar and Driver (1987) stressed that the problem for the assessment of processes is that it poses some validity (and reliability) concerns. Indeed, Woolnough (1994) argued that a dilemma might arise when an attempt is made to tie precise assessment techniques to processes of science and skills. As a result, he maintained that students' proficiency in relation to practical science is susceptible to the tension between reliability and validity in assessment. He went further to illustrate that we might obtain a more reliable measure of the student's ability to read a thermometer accurately, or to record results appropriately on a graph, but that that might not validate the student's ability to execute a real science investigation. Woolnough (1994) added: "Nor it is possible to give genuinely reliable assessment in anything other than the most trivial, atomistic, assessment exercise" (p. 19). Hence, in the light of these debates, Harlen's (1999) and Llewellyn's (2005) views that assessing process skills or inquiry skills are best executed over a prolonged period of time are justified. Such an approach may allow for a "more subtle, possibly, individual, assessment technique" that may provide us with insight on how students arrived at an outcome (Millar & Driver, 1987, p. 54). For Woolnough (1994), a scientific work that "proceeds by intuition, serendipity and imagination, followed by rigorous attempts at disproof" (p. 21) may prove useful. Woolnough (1994) went further to assert that utilisation of individual, problem–solving, practical investigations could provide a context for such a humane model of scientific activity susceptible to excellent results and most importantly holistic assessment divorced from "having to break down the analysis into specific, predetermined, processes and skills" (p. 21).

Another problem (i.e., for the assessment of processes) is that assessment of processes is content and context dependent (Harlen, 1999; Millar & Driver, 1987). Harlen (1999) argued that a student's performance in any scientific investigation would be influenced by the nature of the subject content and the student's proficiency in utilising the associated skill. Millar and Driver (1987) concurred that students often demonstrate considerably higher levels of cognitive functioning in areas of interest, especially in extra–curricular science activities. Arena (1996) also reported that student scientific skills "are more efficiently learned when the context in which the problem is set is familiar and meaningful to the student" (p. 37). Hence, the implication is, a lot of planning ahead is needed on the side of teachers as Fairbrother (1989) suggested. The planning may include providing opportunities for students to develop skills with assessment tasks that are practical, realistic and challenging prior judgements are made (Harlen, 1999) that are based on a particular assessment framework.

The Assessment framework is a tool utilised, for instance, for summative assessment by teachers and students and, as such, enables monitoring and evaluation of students' science process skills (Harlen, 1999). This implies that in the current study, it would have been used to document Expo students' levels of performance on the process skills and Life Sciences concepts. One of assessment framework predecessors was the product of Assessment Production Unit (APU) in the United Kingdom (Millar & Driver, 1987), which itself has been criticised in terms of providing a distorted picture of the authentic scientific investigations (Woolnough, 1994). Ogunniyi and Mikalsen (2004) reported that the APU was set up in 1975 as a large–scale research project under the support of the Department of Education and Science to promote the development of methods of assessing and monitoring achievement. The framework was then able to provide objective feedback concerning the national standards of pupils' performance at all levels of ability. Indeed, Harlen (1999) argued that it was through the APU that key issues emerged with regard to the difficulties in assessing science process skills (i.e., the nature of the subject content, and the ability to use the skills [p. 58]). Nevertheless, the APU framework was developed in response to a need to analyse the component skills required in science. Tytler and Swatton (1992) argued that the framework reflected "a practically–based investigative activity…[an approach whose] underlying message…is that it will develop in students, qualities which are characteristic of practicing scientists, viz being observant, organized, systematic and objective" (p. 22). Table 2.2 presents the APU assessment framework.

Table 2.2

The APU assessment framework (According to Tytler & Swatton, 1992)

The categories of science performance			
1.	Use of graphical and symbolic representation	Reading information from graphs, tables and charts Representing information as graphs, tables and charts	Written test
2.	Use of apparatus and measuring instruments	Using measuring instruments Estimating physical quantities Following instructions of practical work	Group practical test
3.	Observation	Making and interpreting observations	Group practical test
4.	Interpretation and Application	Interpreting presented information Applying: Biology concepts Physics concepts Chemistry concepts	Written test
5.	Planning of investigations	Planning parts of investigations	Written test
6.	Performance of investigations	Performing entire investigations	Individual practical

In South Africa, the assessment framework of the science curriculula is based on the principles of Outcomes–based Education (DoE, 2002). The associated Learning Areas (e.g., Natural Sciences, Life Sciences, etc.) have detailed sections on assessment in place, which are meant to provide indications of student achievement, and to ensure that the student "integrate and apply skills" (DoE, 2002, p. 3). In simplified terms, each Learning Area in the South African science curicula addresses educational outcomes. There are Assessment Standards that reflect increasing growth in students competence in terms of the knowledge, skills and values in different grades (DoE, 2002; DoE, 2003b; DoE, 2003c).

Indeed, the South African curriculum developers expect students to develop and use scientific inquiry and problem–solving skills within the context of an expanding framework of knowledge. The skills "are the focus of science learning and assessment activities in classrooms" (DoE, 2003b, p. 10). They (i.e., scientific inquiry and problem–solving skills), form the basis for assessing the student's ability to explore confidently and investigate phenomena relevant to Life Sciences (DoE, 2003b). Moreover, the students are expected to present reasons for explanations of phenomena and to create relationships between experimental processes and results obtained. They are also expected to make predictions and formulate hypotheses regarding phenomena in order to solve bigger problems (*Learning Outcome 1*). In short, they are expected to not only show proficiency in identifying and questioning biological phenomena but also to conduct science investigations by collecting and manipulating data, analyse, synthesise and evaluate data, and communicate their findings (DoE, 2003b).

The students are also assessed in terms of their ability to access, interpret, construct and use concepts in the Life Sciences to explain phenomena within this Learning Area (DoE, 2003b). Therefore, use of inquiry and thinking skills form the basis for interpretation, application and extension of the students' understanding of concepts, principles, laws, theories and/or models during the construction and application of Life Sciences knowledge. The students are expected to draw from their experiences as they develop Life Sciences knowledge (*Learning Outcome 2*) (DoE, 2003b). In summary, the students are expected to be able to access relevant knowledge in Life Sciences, interpret and make sense of it, and be able to show its application in their everyday life with regard to lifestyle and management of resources (DoE, 2003b).

The abovementioned scientific skills are also further developed in *Learning Outcome 3* as the students are assessed in terms of their ability to demonstrate an understanding of the nature of science, the influence of ethics and biases in the Life Sciences, the interrelationship of science, technology, indigenous knowledge, the environment and society (DoE, 2003b). The students are, therefore, expected to showcase their competence in exploring and evaluating the scientific ideas of past and present cultures, compare and evaluate the uses and development of resources and products and their impact on the environment and society, and compare the influence of different beliefs, attitudes and values on scientific knowledge (DoE, 2003b).

Summary

In summary, important issues related to enacting science process skills in science teaching and learning and their implications for the presented research study of science Expo activities may be considered as follows:

- Science process skills may play a significant role in the contemporary science teaching and learning scenario marked by current challenges opting for lifelong learning. They are capable of eliciting scientific inquiry and problem–solving skills in learners, and these skills are best developed within the context of an expanding framework of scientific knowledge (DoE, 2003b). Furthermore, learners may have an opportunity to develop and demonstrate the ability to think objectively and to use a variety of forms of reasoning while they use process skills. Also, the introduction of science process skills is likely to enable learners to study phenomena with insight and understanding (Rambuda & Fraser, 2004). These important aspects are the basis for the current study.
- This study intended to explore investigative projects within the South African national curriculum context in tandem with ESKOM Expos. Investigations have been hailed as the basis for inquiry that, from the perspective of Wilke and Straits (2005), have many benefits, especially in learning. Most importantly, they can empower learners, particularly in developing proficiency in learning knowledge with insight and understanding; in constructing knowledge as they utilise science process skills; and in developing critical thinking skills (Rambuda, 2002). As the result, a framework of process skills is valuable to teachers in assessment (DoE, 2002).
- Harlen (1999) emphasised the need for assessment in student learning of science. On that note, Woolnough (1994) scrutinised the attempt to incorporate precise assessment techniques to processes and skills. He called for a humane model of scientific activity susceptible to excellent results and most importantly holistic assessment divorced from unattainable paradoxes. In the current study, the Expo students had already engaged as individuals in enquiry–oriented strategies. Hence, I explored whether the students developed the South African curricula–oriented scientific skills and Life Sciences–based learning outcomes as they endeavoured in their respective investigations. The investigations were assessed holistically by incorporating pertinent elements of their life histories.

Chapter summary

In this chapter, I presented pertinent literature in two parts. Learning outcomes form the basis of outcomes–based education and are used to describe what a student should know and be able to demonstrate in terms of, for instance, process skills. As a result, I introduced an overview of theoretical component as well as rhetoric debates and research findings into the processes and skills. The significance of students' proficiency in scientific skills through learning science was also provided. Furthermore, I outlined various potential roles of extra–curricular science activities, such as Science Fairs and Science Expositions, in the teaching and learning of science. Their linkages to the South African science curricula were also addressed. Moreover, I set out the summary of the reviewed literature for the present investigation, and identified research gap in my area of study. The research methodology of the current study now follows in Chapter 3.

CHAPTER 3

RESEARCH DESIGN AND DATA PROCESSING PROCEDURES

Introduction

The purpose of this study is to explore and analyse Expo students' development of scientific skills in articulation with their abilities to utilise them to interpret and use Life Sciences concepts in explaining biological phenomena (Chapter 1, pp. 4, 5). Furthermore, I wanted to gain a better understanding of how the students learnt through their projects. Therefore, I sought to investigate their experiences related to Expos that may have influenced their development and undestanding of the skills and knowledge.

Research approach

In this research study, I utilised a qualitative research approach for generating and analysing data. The principal aim of qualitative research is a sensitivity to the holistic picture and depth of understanding of a particular phenomenon investigated (Ary, Jacobs, Razavieh, & Sorensen, 2006; Denzin & Lincoln, 1998; Lunenburg & Irby, 2008). Indeed, one of the advantages of qualitative research is that it seeks to understand, describe and occasionally explain a phenomenon by, for instance:

- Analysing documents. The documents may encompass texts (Kvale, 2007), such as school students' reports of their projects and completed questionnaires containing in depth information about phenomenon investigated (e.g., skills and knowledge).
- Analysing personal experiences of individuals or groups (Kvale, 2007; Denzin & Lincoln, 1998). This implies that qualitative research uses subjective data to describe the context of the key variables under consideration.

In fact, whereas a quantitative approach, in its attempt to increase generalisability, puts emphasis on analysing variables and the relationships between them in isolation from the context or setting, the qualitative paradigm strives for context and meaning

(Denzin & Lincoln, 2005). It should be noted that a choice between quantitative and qualitative research approaches depends on a research question asked (Patton, 1990). For instance, the current study built on the explanatory research question (Chapter 1, p. 6), which required the qualitative approach over quantitative approach. This adopted approach (i.e., qualitative research approach) also has philosophical basis.

Qualitative research is embedded in, for instance, the constructivist philosophy (Denzin & Lincoln, 1994, 1998). Mabry (2009) and Nieuwenhuis (2007) argued that qualitative studies imply the constructivist theory that students built construction of reality by attaching meaning to a particular phenomenon investigated. As the result, the present study strived for meaning Expo students constructed in relation to their scientific skills (e.g., process skills) and different biological concepts. Denzin and Lincoln (1998) and Mabry (2009) also implied that such meaning is also embedded in students' experiences. Through an interpretive lens, school constitutes lived experiences. Consequently, it was essential that the current students' mentors be contacted to provide corroborative evidence of the students' lived experiences at school.

Qualitative research has its own methodological principles related to methods of collecting evidence. It should be noted that it acknowledges the researcher as the prime instrument of investigation (Neuman, 2006). It should also be noted that qualitative approach methods are meant to describe patterns of behaviour or learning patterns by accessing the intentions, actual words, experiences and perspectives embedded in them to unravel their meanings (Ary *et al*., 2006; Snape & Spencer, 2003; Fraekel & Wallen, 2000). This implies that inquiries are accomplished through fieldwork methods that provide rich, thick and detailed data that "[fit] for purpose" (Cohen, Manion, & Morrison, 2007, p. 181) from cases that are purposively selected and small in scale (Ary *et al.*, 2006; Snape & Spencer, 2003). The data collection techniques that are used to produce textual data related to predetermined educational outcomes (e.g., skills and knowledge) may include, for instance, different forms of interviews (e.g., semi–structured), life histories, video and audio recordings and document analysis (Cohen *et al*., 2007).

Cohen *et al*. (2007) pointed out that most qualitative research tends to be naturalistic and holistic. Green (1998) asserted that the implication of qualitative research's holistic approach includes – in addition to embracing sensitivity to context and process – an inductive approach to analysis, flexibility in research design and a commitment to understand rather than to prove or to promote. This implies that the inductive approach recasts scientific notions of research design. It is an individualised process and allows for evolvable designs and, as such, avoids researchers "getting locked into rigid designs that eliminate responsiveness" (Fraekel & Wallen, 2000, p. 503). For instance, the researcher may collect new data, as supplementary data is required due to new insights discovered and/or change the research question(s) to fit the study's updated objectives.

As referred to earlier, a qualitative research assumes inductive approach to analyses of data. This implies that, theory or explanation generation can be emergent, hence it is more inductive than content analysis (Dawson, 2006). The advantage of analytic process in qualitative research is that it allows a researcher to select suitable ways of organising and presenting data analysis. For instance, it allows a researcher to focus on the responses of an individual and then synthesise the issues arising across the individuals in order to come up with, for instance, common factors or themes before summarising the data (Cohen *et al*., 2007). Cohen *et al*. (2007) also indicated that all relevant data gathered through different methods (i.e., interviews, questionnaires, document analysis) are collected to elicit, for instance, patterns that may provide a collective answer to a research question. Drawing on Denzin and Lincoln (2008), a qualitative approach evidently requires a strategy that is "inherently multimethod in focus" (p. 7).

It is thus on the basis of the aforementioned relevant characteristic features of qualitative research that this study is framed. Neuman (2006) also argued that qualitative researchers tend to use a case–oriented approach that places cases, not variables, as their basic research technique. The researchers also have the opportunity to draw from peoples' personal experiences, life histories and case study documents to explain phenomenon under investigation (Denzin & Lincoln, 2005).

Case studies

Qualitative research, as a mode of inquiry, is a "site of multiple methodologies and research practices" (Denzin & Lincoln, 1998, p. 5). I drew upon qualitative case studies, as a research technique, because they are known to comply with the three principles of the qualitative method: describing, explaining, and understanding (Yin, 2009). Cohen *et al*. (2007) and Mabry (2009) summarised a case study as a specific instance of a bounded system that provides a unique example of phenomena in its real context, enabling readers to understand ideas beyond just statistical generalisations. Case studies have a specific purpose: "to portray, analyse and interpret the uniqueness of real individuals and situations through accessible accounts" (Cohen *et al*., 2007, p. 85).

Cohen *et al*. (2007) summarised strengths of case studies that make them popular with educational researchers. For instance, case studies are strong in portraying reality. Indeed, they are the best approach in portraying a full picture of participants' "lived experiences of, thoughts about and feelings for a situation" (Cohen *et al*., 2007, p. 254). Case studies' strength is also in their ability to speak for themselves. The reality portrayed is drawn from the case itself rather than to be largely interpreted, evaluated or judged by the researcher (Cohen *et al*., 2007). In case studies, "[thick and detailed triangulated sets of data] and astute insight into the cases [in their real–life contexts] replace the sophisticated statistical analysis of precise measurements across a huge…cases found in quantitative research" (Neuman, 1996, p. 159). These unique features provide the basis for understanding the situation (Cohen *et al*., 2007). Therefore, case studies set a tone for descriptive and detailed accounts of the participants' experiences, "with narrow focus, combining subjective and objective data" in their responses from multiple sources of evidence (Cohen *et al*., 2007, p. 254). Such evidence may be gathered from, for instance, documents, interviews and physical artifacts (Yin, 2009). Cohen *et al*. (2007) also argue that case studies can provide insight into other, similar situations and cases thereby assisting interpretation of similar cases. This implies that they can allow generalisation emanating from multiple cases.

Case studies can be single or multiple–case designs (Denzin & Lincoln, 2008; Yin, 1994). Even though multiple–case designs are demanding in terms of resources and time, Yin (2009) pointed out that "*evidence* from multiple cases is often considered *more compelling*, and the overall study is therefore regarded as being more *robust*" (p. 53; emphases added). Most importantly, Yin (2009) argued that the analytical benefits of working with several cases are considerable compared to that of a single case. Hence, several case studies were used on the basis of these relevant characteristic features coherent with the characteristics features of the multiple–case approach.

Life histories

Qualitative approach's principles, which fit in case studies, offer an opportunity for analysis of experiences. Such experiences can be related to biographical life histories (Kvale, 2007). Life histories – which are also known as narrative studies, biography, life stories, life narratives or oral histories – are defined as first–person accounts of experiences based on spoken conversations or interviews (Ary *et al.*, 2006; Denzin, 1989; Neuman, 2006). The experiences are related to an event in the past or expectations for the future (Nilsen, 2009). Therefore, I also applied life histories to explore and document the individual students' experiences at home and at school, and their future aspirations realised through Expos. Moreover, narratives, as Babbie and Mouton (2001) asserted, could fit perfectly in case study method. Consequently, they became the essential components of the case studies I adopted to merely explore and analyse Expo students' educational outcomes, in the first place.

Life histories' trustworthiness relies on representation of the cases' perception of a situation (Cohen *et al*., 2007). To account for this, I did not rely solely on Expo students' interviews for their experiences. Their Expo reports and their written questionnaires were utilised for corroborative evidence on their perceptions of the Expos, their individual work and themselves.

To sum up, I chose to frame my study on qualitative research and the associated case studies and life histories for the reason that:

- They enabled me use Expo students' documents and other sources of personal information to portray a vivid pictures of sections of their lives, and
- They enabled me elicit details, insights and explanations regarding Expo students' development and understanding of scientific skills and Life Sciences concepts related to different phenomena investigated.

Research methods

In this section, I outline all the stages I followed in the research process. These encompassed the kind of data I needed in order to answer the research questions (Chapter 1, p. 6), specific data collection strategies and ethical measures employed in the study, measures taken to ensure trustworthiness of the study's results, and organisation and presentation of data analysis procedures.

The nature of data to be collected and appropriate data collection strategies

As described earlier, my study was embedded in qualitative research framed on case studies and the associated life histories. I needed information regarding the details of Expo students' process skills and scientific knowledge they developed. Content analysis of documents (i.e., Expo project reports and completed questionnaires) was suitable for this type of inquiry (Yin, 2009). Moreover, interviews were also used as they provided me with more insights (that is, they provided "perceived causal inferences and explanations" [Yin, 2009, p. 102]) regarding the skills and knowledge contained in the documents analysed. I also needed information regarding the students' experiences related to the Expos. The interviews were utilised because they could provide me with insights, which were now related to the experiences (Yin, 2009).

There are many sources of ideas of student projects (So, 2003). Such ideas might include the observations made of events that occurred within and beyond the classroom (Ogunniyi & Mikalsen, 2004). Students' life histories may elicit sources of such important ideas. Consequently, the first research question was based on the students' life histories, that is, factors that shaped the students' participation in the Expos. The students' and their mentors' personal *interviews* were to produce data that would answer this question.

It should also be noted that "[scientific skills (e.g., process skills)] are best developed within the context of an expanding framework of knowledge" (DoE, 2003a, p.10). Indeed, process skills are demonstrable and that they entail the use of concepts (Ogunniyi & Mikalsen, 2004). The implication is that: (a) process skills "have to be used in relation to some content" (Harlen, 1999, p. 131), and that (b) students' proficiency in process skills and science concepts can be inferred from actions, such as verbal (i.e., through personal interviews) (Ogunniyi & Mikalsen, 2004) and written responses or written work (e.g., a questionnaire and/or Expo report) (Molefe, 2007, 2008; Ogunniyi & Mikalsen, 2004; So, 2003). Hence, personal *interviews* and *content analysis of documents* were to produce data that would answer the second research question, which was framed around scientific skills (e.g., process skills) and Life Sciences knowledge of Expo students. The third research question was based on the possible articulation between the Expos, the science curriculum and science classroom practices. The students' and their mentors' personal *interviews*, and *content analysis of documents* were to further produce data that would answer this question.

The multiple data collection strategies stated above formed the basis for a technique that is strongly recommended in case studies, namely triangulation (Yin, 2009). Triangulation refers to “the use of two or more methods of data collection in the study of some aspect of human behaviour” (Cohen *et al*., 2007, p. 141). I used it because it is generally acknowledged as one of the best strategies to add rigor, breadth, complexity, richness, and depth to one’s investigation in qualitative research (Denzin & Lincoln, 2005). Indeed, the technique enabled me to “**triangulate** the ‘true’ state of affairs by examining where the different data [from the interviews and the content analysis of documents] intersect” (Silverman, 2010, p. 133; emphasis in the original) in the cases I selected.

Selecting cases and sites of the investigations

Expo participants were the key informants in this study. They comprised four females and one male. They were English first language high–school students, with an age range of 15 years to 18 years. These participants were Grades 10-11 students from three high schools in the Western Cape (Chapter 1, p. 18). They were recruited by their mentors to participate in the 2007 Expos. Table 3.1 presents the participants and the schools who took part in the study.

Table 3.1

Students and the schools that participated in the research study

Expo students*	**Mentors***	**Schools***
1. Alina	Mr. Paul	Western Cape High School
2. Elizabeth	Ms. Nicola	St. Peter’s Grammar School
3. Felicia	Mr. Daniel	Protea High School
4. Gertrude		
5. Henry		

* The names of the participants, mentors and the schools are pseudonyms.

The three mentors were contacted because they were Physical/Life Sciences teachers with vast experience in mentoring Expo students. It should be noted that their key role in this study was merely to substantiate and/or add on their respective students' reports on own science learning experiences in their respective schools.

Criteria for selection of cases

When selecting cases, theoretical/purposive selection of informants is recommended (Mabry, 2009) and it is determined by, for instance, the research focus (Silverman, 2010). Consequently, I employed purposive selection of informants for the reason that it enabled me select cases from a pool of Expo participants, who – I anticipated – could provide me with relevant information (pp. 67-68). Indeed, Expos in the Western Cape, particularly the Cape Town region, have continuously produced participants who represented the country internationally (Chapter 1, p. 3). Therefore, I anticipated that I would obtain rich, in–depth data from the Expo students' projects as well.

Silverman (2010) showed that when selecting cases, setting also determines the criteria for selection. I also adapted the variation of purposive selection of informants namely convenience. Convenience was employed on the basis of the location of competitions and ease of access to the Expo participants' exhibitions at the 2007 ESKOM Expos for Young Scientists (Mabry, 2009; Ary *et al*., 2006).

The cases themselves were chosen on the basis of the participants' willingness to participate in the study. The volunteers agreed to be interviewed, complete a questionnaire, and allow access to their project reports.

The cases were also selected on the basis of the status of the participants' projects – that is, only medal–winning projects whose categories were under Life Sciences (Chapter 1, p. 8). The projects were chosen over other Learning Areas projects, such as Physical Sciences because:

- Both the researcher's expertise and the study's focus are in Life Sciences.
- High–school students can also develop valuable scientific skills, such as observing and interpreting science information, and biological concepts in "science fair experiments and any other independent project" set in a biological context (Kovac, 2001, p. 43). In fact, DoE (2003a) asserts that students' scientific skills in Life Sciences can be best developed within the context of an expanding

framework of knowledge.

Regardless, I encountered a few challenges regarding the selection of the cases, especially at the Cape Town Expo. I considered all the categories under Life Sciences at the Expo. However, as it was the case during stage two of the pilot studies (p. 75), I ended up with a limited number of students who were willing to work with me. Consequently, this challenge determined:-

- The *quantity* of my cases: I ended up with merely five projects.
- The *gender* of the participants: The volunteers were virtually females.
- The *project categories* I used in this study: The projects I had access to were categorised under health care and medical sciences.

It should be noted that I considered ethical measures throughout the study, yet the measures could not alleviate the challenge. In St. Peter's Grammar School, there were 14 award–winning projects. A total of nine students from the school volunteered. Five of them were, however, not comfortable with the interviews. Four who could provide all the sources of data either had a project not categorised under Life Sciences or had a project that lacked a practical part of an investigation. One project was thus used (Elizabeth's). It was in Protea alone that I had more than one project to use (three medal winning students volunteered).

Ethical measures

It was important to take into account ethical considerations throughout this study. Hence, the moral imperative of adhering to the participants' rights was exercised in the current study. Punch (1998), Ary *et al.* (2006), and Cohen *et al*. (2007) proposed a set of considerations of how to deal with ethical issues in educational research. According to them, researchers need to address issues around relationship with the participants (e.g., anonymity and confidentiality), and permission to conduct research (e.g., informed consent and access and acceptance).

In order to address these issues related to relationship with the participants and permission to conduct research, the following measures were executed:

- The right to privacy is an integral part of the conduct of ethical research with human participants (Punch, 1998; Ary *et* al., 2006). Consequently, I designated the individual Expo students, their mentors and their schools pseudonyms (i.e., fictional names for the Expo participants; fictional names for their teachers/mentors; and fictional names for their schools [Table 3.1, p. 69]) to retain their anonymity. I provided the students with signed consent forms (Appendix A), and the mentors with signed letters (Appendix B). The forms and the letters contained information regarding non–disclosure of the participants, their schools and the material in, for example, the video/audio–recorded interviews for any purpose other than the research study.

- Yin (2009) also suggested that researchers should gain informed consent from all persons who may be part of a research study, by disclosing to them the nature of the research study and formally soliciting their volunteerism and the associated understanding of the mutual obligation regarding the research. I used the consent forms to articulate the purpose of the research study to the participants (as well as the principals, teachers/mentors and/or parents). Cohen *et al*. (2007) warned that respondents should not be persuaded into completing a questionnaire. This was addressed in the consent forms attached to a questionnaire administered to the Expo students (p. 76). Indeed, the participants (and the mentors) were reminded of the issue of volunteerism and their obligations regarding the study before the personal interviews. The Expo students and either their parents or their science teachers/mentors signed the forms. I offered to answer any questions regarding the nature of the study and the methods implemented. The participants were also informed through letters sent to their schools (seeking permission from their respective schools' management) (Appendix C) that the participation in the current study was also voluntary. Furthermore, permission to conduct the research was sought from the organisers of the Western Cape Expos (Appendix D). Ethical clearance was also obtained from the University of Cape Town as part of seeking permission to commence with my research study.

Data collection strategies

In qualitative research, case study evidence emanates from six sources which include, for example, documents and interviews (Yin, 2009). Yin (2009) went further to argue that benefits from the sources of evidence could be maximised if principles of data collection are used properly. One of the principles is the use of multiple sources of evidence. Hence, the following pertinent data collection strategies were employed in this study: Personal interviews, and document analysis (i.e., content analysis of questionnaires and of Expo reports; p. 68).

The questionnaire and Expo reports were useful on account that students' written work can provide essential evidence if the students "are asked to *describe* their observations, predictions, and plans, and how they carried them out" (So, 2003, p. 180; emphasis added). Indeed, Tytler's (1988, 1992) case studies related to independent research projects showed that a student *questionnaire* can complement *interviews* successfully when eliciting descriptions of their project work and personal experiences from their perspectives. Furthermore, Dechsri, Jones, and Hikkinen; Fraser, Giddings, and McRobbie; and Watson, Prieto, and Dillon (as cited in Rollnick, Zwane, Staskun, Lotz, & Green, 2001) believe that students' work (i.e., written questionnaires and *written products of practicals*), together with interviews, can provide insights into what actually happened during the students' practical sessions/investigations as well as revealing valuable information about their pertinent life histories. The combination of the interviews and documents became useful in providing both complementary and supplementary results on the Expo students' experiences related to their projects, and on their understanding of Life Sciences concepts and details of their performance regarding science process skills. Before I present each data collection strategy, it is important that I outline how they were piloted.

Pilot phase of the study

According to Neuman (2006), "the principle of pilot tests extends to replicating the measures other researchers have used" (p. 191). Tytler's (1992) study showed that *questionnaires* and *interviews* can be used in case studies to elicit, for instance, students' views of independent research projects (IRP), the state of their knowledge in IRP, and sources of their inspiration and support for their projects. On the other hand, So (2003) showed that with use of an analytical framework for content analyses of students' work, *students projects* can be used to elicit the students' understanding of scientific concepts, details of their performance regarding science process skills, and experiences related to their projects (i.e., origins of ideas for their projects). Pilot studies conducted were enlightening in terms of utilisation of these sources of evidence. Indeed, they were useful in terms of content of data to be gathered, procedures to be followed, development of relevant lines of questions, and on whether the research design needed modification (Yin, 2009).

The pilot studies were conducted in Cape Town for the period March 2006 to May 2007. I adhered to the essential ethical considerations during the entire study (pp. 71-

72). Three stages of the pilot phase are outlined in Figure 3.1.

Stage one: The first pilot study was conducted in Cape Town in 2006. Two medal–winning projects were used to evaluate the viability of Expo projects in enabling the students' development and expression of the learning outcomes and the scientific skills of the South African Natural Sciences, Life Sciences and Physical Sciences. I engaged the services of several of volunteer science teachers at the University of Cape Town at the beginning of 2006. Working as a group, they analysed the learning outcomes of the Expo reports of two medal–winning investigative projects – one in Life Sciences and one in Physical Sciences. The reports were selected from among 20 winners who participated in the 2005 ESKOM Expo in Cape Town. The teachers' content analyses of the Expo reports in regard to educational outcomes (i.e., scientific skills, technological skills, processes, and knowledge) were compared with my own. Molefe (2007) provides evidence regarding an Expo project's *viability* to show the educational outcomes developed by school students.

Stage two: The second pilot study was conducted at the Cape Town ESKOM Expo held in the University of Cape Town in August 2006. The main focus of this stage was on the effectiveness of a *triangulation technique* – in which a questionnaire, interviews and students' Expo project reports were used – in providing corroborative evidence regarding students' development of skills and knowledge. The student volunteers comprised six junior school (Grades 8–9) and sixteen senior school (Grades 10–12) Expo participants in the animal and plant sciences categories.

Expo exhibitions are run over two days. The first day is assigned for primary (Grades 6–7) and junior school students and the second day for the seniors. I invited all the students in the two Life Sciences categories for the interviews and the questionnaire sessions, which were both captured with a video camera. Willing and interested student volunteers completed the questionnaire and were interviewed at their respective exhibition stations to enable them share relevant information related to their exhibitions. Permission was sought from the organiser of the Expo. The Expo students agreed to the video recording of the sessions.

In the first place, analysed responses of the primary and junior school students (considering their cognitive level) were utilised to *refine* the interviews and questionnaire schedules so as to use improved tools to collect data with the senior school students the following day of the senior Expo participants' exhibitions.

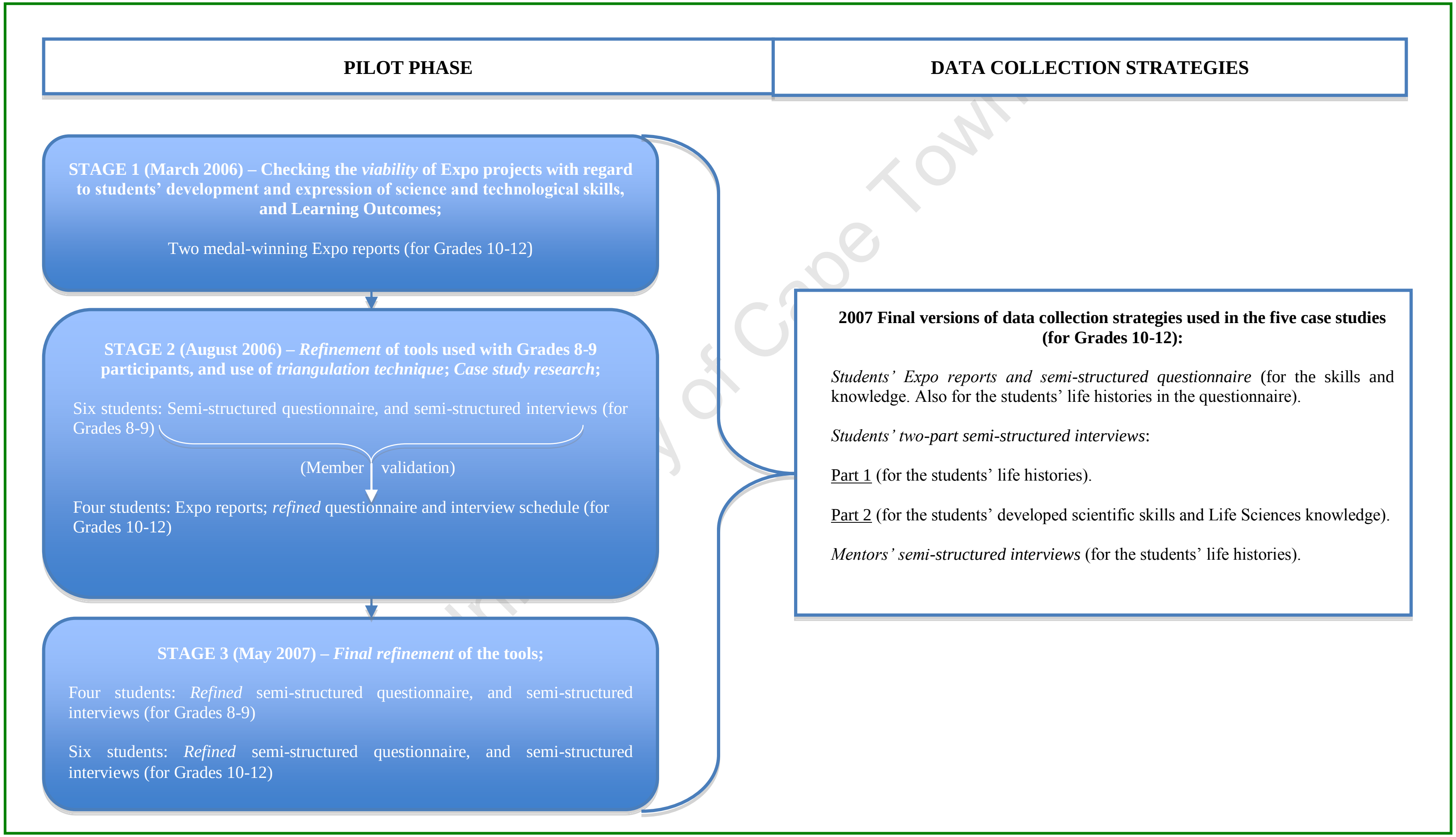

Figure 3.1 The pilot phase of the study and the data collection strategies ultimately employed.

Moreover, it was important that I use semi–structured interviews with the Expo students because they are suitable for one session interviewing (Bernard, 2006). A volunteering PhD student who had several years' experience of Expo assisted in refining the tools overnight (e.g., developed unambiguous and relevant lines of questions). Molefe (2008) provides evidence that showed that the *triangulation technique*, which was only applied to the projects of senior school students, should be adapted during the main study. However, regardless of the success of the technique during this preliminary study, it was evident that more Life Sciences categories than those of plant and animal sciences should be considered to counteract challenges related to access (e.g., a drop in the students' enthusiasm in relation to the interviews, and limited access to the students' Expo reports). Indeed, I had access to merely four Expo reports of the senior school students after the 2006 Expos. Furthermore, it was also evident that more information was lacking in terms of the factors that shaped the students' participation in the Expos in the first place. This further justified the choice of a *case study research design* over a survey. The choice of the case study approach also influenced me to collect supplementary information regarding the students' experiences at school from the students' mentors during the main study.

Stage three: The final pilot study was conducted in May 2007. The questionnaire and the students' interview schedule that were used in stage two were subjected to *final refinement*. The intention was to pilot these tools further prior to the collection of data with the senior Expo students at the two main ESKOM Expo venues in the Western Cape in August of 2007. The sources of evidence were now: (a) a thin pamphlet–like questionnaire containing items that also addressed the students' Expo experiences in addition to their skills and knowledge; and (b) two–part interview schedule, which averaged 25–35 minutes per student (p. 79). Three junior school (Grade 9) and four senior school (Grade 11) Expo participants from one school in Cape Town were invited to participate in the interviews and to complete the questionnaire.

Implementation phase of the study

The final data collection strategies that were used during the main study with the five case studies included the questionnaire and the two–part interviews, which were both semi–structured (Figure 3.1, p. 75).

The Expo students' questionnaire

Questionnaires are commonly used in quantitative studies, however Babbie and Mouton (2001) stated that they are also applicable to other research designs such as qualitative–oriented studies (e.g., case studies) in which "rich and personal data are sought" (Cohen *et al*., 2007, p. 321).

The purpose of questionnaires can be to explore, for instance, peoples' perceptions, attitudes, understanding, knowledge, values, feelings and experiences (Black, 1999). Indeed, Tytler (1988) showed that aspects such as sources of ideas for students' projects, assistance the students obtained during the projects, challenges and problems they encountered, their perceptions of independent research projects, and the state of their knowledge and skills, could be collected by using questionnaire data. I used the questionnaire as a data collection strategy in this study for two reasons. De Leeuw (2009) argued that, unlike interviews, self–administered questionnaires are less intrusive as the researcher is not involved in the question–answer process. This characteristic feature of questionnaires implies that respondents may have more privacy and time to consult, for instance, their reports to provide accurate responses (de Leeuw, 2009). Cohen *et al*. (2007) suggested partially structured questionnaire. They argued that "the semi–structured questionnaire sets the agenda but does not presuppose the nature of the response" (p. 321).

The aforementioned arguments were instrumental regarding the use of a questionnaire as a data collection strategy. It should be noted that the study's research questions were focused on factors that shaped the students' participation in the Expos, and the students' understanding of Life Sciences concepts and the process skills they used in their respective projects. The following are the topics which were framed around these two key questions (Appendix E):

- Reasons behind their participation in Expos.
- Their inspirations to start their Expo projects.
- What made them think they could do the projects.
- Skills they thought they had learnt during the course of their investigations.
- Science process skills: These included those skills that were more challenging to both junior and senior students (at pilot stage) namely, hypothesising, sorting and classifying, and predicting.
- Their perceptions of science and/or scientific investigations.

Evidently, I administered a semi–structured questionnaire that was clearly structured, sequenced and focused but enabling the students to comment in a way that they thought best or reply in their own terms (Cohen *et al*., 2007). The students were allowed to complete the questionnaire at their spare time so that they might provide well–considered responses on their Expo experiences and educational outcomes (i.e., Life Sciences knowledge and process skills). The questionnaire was a three–page pamphlet to optimise the students' responses.

It should be noted that the questionnaire was meant to produce documentary data for comparison with the ideas, understandings and explanations that might be obtained from the interviews and the students' Expo reports. However, they were limited because they did not allow probative follow–up questions into the students' written responses, especially where the students interpreted the questions differently. Indeed, the insights into students' understanding of Life Sciences concepts, details of their performance regarding science process skills, and experiences related to their projects in terms of Expos, their homes, and their schools were limited. In order to compensate for these shortcomings in the questionnaire, I used semi–structured interviews.

The mentors and Expo students' personal interviews

An interview is a versatile tool for data collection in which multi–sensory channels are used (Cohen *et al*., 2007). Mentors and Expo students' personal interviews were used as a second data collection technique because they were likely to provide me with more in–depth data than questionnaires. After all, "[interviews] are the most important sources of case study information" (Yin, 2009, p. 106).

Interviews have specific purposes. They focus a researcher to evidence that has a direct bearing on the research study's line of inquiry (Cohen *et al*., 2007). Cohen *et al*. (2007) went further to say that researchers purposely use them with other sources of evidence to validate those sources, or to provide both complementary and supplementary information regarding the objectives of a research study. The latter (i.e., provision of information), in particular, is neccesiated by the fact that interviews, "by providing access to what is 'inside a person's head', makes it possible to measure what a person knows" (Cohen *et al*., 2007, p. 351). Indeed, Yin (2009) argued that interviews strength is actually in enabling researchers to get insight into and/or to corroborate certain facts that one has established. In extra–curricular science activities, partially structured interviews could also be used for the purpose of eliciting students' own stories of their projects and the nature of the associated experiences (Tytler, 1992).

There are several features of interviews that made them the appropriate strategy to collect data with the Expo students and their mentors. Firstly, interviews provide in–depth understanding of the participants in a naturally established field setting (Fontana & Frey, 2005). However, Fontana and Frey (2005) also illustrated that, in interviews, a researcher may not have a fixed setting due to, for instance, access related challenges. Secondly, Ary *et al.* (2006) argued that qualitative research interviews could provide one with sufficient in–depth data needed rather quickly. Indeed, Cousin (2009) added that interviews (e.g., semi–structured) allow probes and follow–up questions, which normally "ask for more information, some detail, an illustration, an explanation, an exception to rule, etc." (p. 87). Furthermore, interviews allow exploration of new ideas unanticipated by an interviewer (Cousin, 2009). Thirdly, Denzin and Lincoln (1994, 2005) argued that because it is difficult for any single method to capture rich data needed, a combination of the methods should be considered. Burns (1997) and Nieuwenhuis (2007) suggested partially structured interviews because they are commonly used in qualitative research studies to substantiate data drawn from other data sources. Furthermore, they allow use of a guide (i.e., set of themes), which according to Bernard (2006), is essential for "reliable, comparable qualitative data" (p. 212).

The current Expo student interviews had two distinct purposes. Drawing on Denzin and Lincoln (2008), Expo students' activities might have been influenced by contexts. Such contexts needed to be explored. In order to obtain the sufficient in–depth data on the students' understanding of Life Sciences concepts, details of their performance regarding science process skills, and experiences related to their projects, the interviews were structured into two parts – Part 1 and Part 2 (Appendix F).

In relation to the exploration and documentation of Expo students' experiences in this study, the purpose of the interviews was to engage, understand and interpret the participants' experiences and motivations (Silverman, 2010), and future aspirations (in Part 1). This information was necessary, as it enabled me to document *factors that shaped the students' participation in the Expos*. The subsequent findings regarding, for instance, science activities at school were further validated through their mentors' individual audio–recorded interviews (Appendix G). The mentors' interviews also provided additional relevant information (i.e., Expo related ethos in the participants' respective schools). Each mentor's interview averaged 10 minutes.

In regard to the students' educational outcomes, their purpose was to gather, understand and interpret *scientific knowledge* of these students inherent to their investigative projects (in Part 2). Furthermore, their purpose was to elicit their awareness and the associated descriptions of their *scientific skills* in relation to, for example, their results, graphs, charts, evaluations and conclusions (Part 2). This information was also necessary, as it enabled me to document the state of the students' skills and knowledge.

I questioned and probed the students either at the Expo exhibition (Elizabeth), at school (Felicia, Gertrude and Henry), or at the University of Cape Town (Alina). It was basically at the Expos where I intended to obtain, from the participants, the in–depth descriptions of their work prior to their presentations. However, the current participants' mentors granted me access to the students (and their projects) at different settings. This flexible approach proved useful in maintaining access to the limited projects in place for in–depth data. It should be noted that the mentors, apart from Nicola who preferred to respond to the interview questions through e–mail, were themselves interviewed at their respective schools.

Although I had limited time to probe the students about their projects, I was able elicit, from the students, the in–depth data I wanted in 25-35 minutes granted to me by mentors and/or Expo organisers to conduct the research. The Expo students agreed to the video recording of the interview sessions. Video recording the interviews proved to be a useful technique because the subsequent videotapes enabled me to fill the gaps in instances where the conversations were not audible. This was not the case with audiotapes alone, which were produced during interview sessions with the mentors.

Document analysis

Documents are written materials, which we scour for information about the key issues we wish to study (Prior, 2009). In the current study, Expo reports are examples of documents. Students present these documents at the Expos as part of their exhibitions. Drawing on ESKOM Expo for Young Scientists (2011), judges and researchers may scour their contents for, for instance:

- *Knowledge and understanding* of phenomenon under investigation.
- *Originality* in an investigative procedure and authentic *scientific innovation* while *acknowledging guidence given*.
- *Creativity in communicating science information* related to the project.
- Good science that follows *the scientific method* which includes different steps, scientific processes and scientific definitions.
- Investigations that have *applications to everyday life*.
- *Understanding of the investigation* and its limitations.

In case studies, the purpose of documents provides us with an insight into their strengths. They are valuable sources of evidence because of their ability to corroborate evidence from other sources (especially in the interest of the crystallisation of data), and to provide insight on phenomena investigated (Maree & van der Westhuizen, 2007; Nieuwenhuis, 2007). Documents' strength is in their ability to provide considerable details about phenomena investigated than interview data (Burns, 1997). After all, they may provide one with exact details of aspects (e.g., exact names, references, details of an event) that might have been mentioned in an interview (Yin, 2009). Indeed, Nieuwenhuis (2007) argued that documents may include all types of communication connected to the investigation. Yin (2009) added that one can make inferences from documents. Yin (2009) went further to say that "documents can provide other specific details to corroborate information from other sources" (p. 103), especially in cases where there are mismatch between methods used in terms of evidence gathered.

I used content analysis of the students' Expo reports as a third data collection technique for the abovementioned reasons. For isntance, the reports were likely to provide me with considerable details, especially of the students' skills and knowledge, than the interviews and the questionnaire. Content analysis of the documents was also used in analysing the students' completed questionnaires. Details of what I did in relation to content analysis of the documents used in this study are presented in the sub–section – data analyses (pp. 86-88).

All these data collection strategies used were instrumental in the methodological triangulation technique, which was part of the measures employed to ensure the study's rigor.

Measures to ensure trustworthiness of the qualitative research approach used

Ary *et al.* (2006) emphasised the importance of rigor in qualitative research. Ary *et al.* (2006) and Cohen *et al*. (2007) summarised that an argument of one's meticulousness in qualitative research is determined by credibility, transferability, confirmability, dependability of the study and/or results.

Credibility of the results

Ary *et al.* (2006) and Silverman (2010) described credibility of the results in terms of the established confindence in the findings of a particular study, with special reference to its research design, participants, and context. In case studies, *triangulation* and *validation* are used to articulate efforts made to enhance credibility of the results (Mabry, 2009; Cohen *et al*., 2007). In the current study, it was essential that I subject interview evidence to every possible test (Silverman, 2010) before I made conclusions about the students' development and understanding of scientific skills and Life Sciences concepts. Indeed, the interviews and the questionnaires revealed students' shortcomings in their understanding of certain process skills in the context of Expos. On the other hand, a review by critical human resources with expertise in the phenomenon investigated or cases used or methodology adapted was also essential (Mabry, 2009). Hence, I engaged the services of two experienced university professors. Their review proved useful in providing not only specific details to corroborate information from the sources used, but also on clarity of the questions and on whether there were sufficient evidence from the sources.

Transferability of the results

Transferability denotes a study's results and their applicability to another context (Gobo, 2009). The current study's aim was not to generalise how Expo students should learn through Expos. Regardless, Ary *et al.* (2006) still warned that descriptive adequency is essential in case studies so that readers can make their own judgement in relation to the study's transferability. Gobo (2009) argued that it is on the basis of, for instance, "argumantative logic and a thick description (of the case study) produced by the researcher [that a reader can decide whether the current knowledge can be transferred to other contexts (considered similar by the reader)]" (p. 197). Gobo's (2009) arguments on logic and description have been adhered to in this study, and the information of the cases used has been discussed in the light of similar cases from the published literature.

Confirmability of data

Confirmability is often taken as synonymous with a researcher's objectivity (Denzin & Lincoln, 2005). In qualitative research, the extent to which a particular study is free from interests, biases, motivations in the procedures and interpretation of results determines confirmability (Ary *et al.*, 2006). Lincoln and Guba (1985) suggested confirmability audit trail which, according to them, safeguard against interests, biases, motivations in the procedures and interpretation of results. My audit trail consisted of reported preliminary findings (i.e., Molefe, 2007, 2008) at pilot phase, and an account of the development of the subsequent factors/themes related to the students' Expo–related experiences at implementation phase. The adapted triangulation of data provided corroborative mechanism which, according to Ary *et al.* (2006), is essential in confirmability.

Dependability of the study

Qualitative researchers acknowledge the importance of evolving or changing interactions between the researcher and the phenomenon studied (Neuman, 2006). On the other hand, Ary *et al.* (2006) argued that the consistency in terms of the extent to which the variations resulting from the interactive process, in the same or similar context, can produce similar results determine dependability. Likewise, in addition to the documentation of the development of the themes (pp. 84-86), triangulation technique remained the basic corroborative technique in addressing the study's dependability.

Data analyses

There are many different types of qualitative data analysis (Dawson, 2006). Case studies involve the utilisation of multiple methods of data collection. Triangulation is, therefore, recommended during qualitative data analysis. I used several qualitative approaches to systematically analyse data for themes, categories and codes that were representative of the experiences, perceptions and activities attributed to Expo students learning. According to Ary *et al*. (2006), the systematic analyses should involve organising and getting familiar with data so that coding and recoding process can run smoothly, prior to deducing what is emerging out of the data, and extract meaning and insights from the data.

Interviews

The purpose of the interviews of the student and mentors was to gain in–depth insights into Expo students' understanding of Life Sciences concepts, details of their performance regarding science process skills, and experiences related to their projects. Indeed, Nieuwenhuis (2007) argued that "[qualitative data analysis] tries to establish how participants make meaning of a specific phenomenon by analysing their perceptions, attitudes, understanding, knowledge, values, feelings and experiences in an attempt to approximate their construction of the phenomenon" (p. 99). Cohen *et al*. (2007) showed that discovering themes is an essential factor in qualitative data analysis. Hence, I analysed the interview data for factors or themes (the steps taken are provided below). As the themes materialised from diverse and in–depth experiences of the students (Bradley, Curry, & Devers, 2007), they provided me with insights into factors that shaped the students' participation in the Expos. Four factors emerged from the interview data. It should be noted that literature reviews on students learning through school projects became instrumental in the analysis. For instance, findings in Tytler's (1992) and So's (2003) publications formed the basis for the factor/theme – The students' origins of ideas to investigate biological phenomena (Chapter 4, p. 91).

Several steps were adhered to during the process of analysis:-

Step one: It should be noted that I used participants' accounts gleaned from audio and video–recorded interviews, to interpret the meaning embedded in my units of analysis (cases). I utilised both manual and computer assisted methods to execute the analyses. I employed word processors for production of transcripts from mentors' and students' interviews. Indeed, Nieuwenhuis (2007) stated that it is essential that data from audio and video–recorded interviews be transcribed. Silverman (2010) also pointed out that transcription of audiotapes and videotapes are usually carried out before (and as part of) the analyses of interview data. Furthermore, Miles and Weitzman (1994) stated that word processors are one of the common software types, which are basically designed for production and revision of text.

Step two: I read the transcripts several times then to understand the embedded data in context. This was essential, as "commitment to theorizing about data makes the best qualitative research far superior to the stilted empiricism of the worst kind of quantitative research" (Silverman, 2010, pp. 247-248). Context is one of the issues associated with theorising about data.

Step three: The read transcripts were then saved as rich text format for the purpose of computer–assisted coding. It should be noted that I utilised qualitative data management software – Nvivo – for thematic analysis of the data. Cohen *et al*. (2007) stated that Nvivo "can search for and return text, codes, nodes and categories" (p. 489). Furthermore, my interviews were partially structured. Hence, the purpose of the Nvivo utilisation was mainly to verify theory gleaned from questionnaire data. Nevertheless, I created the nodes and connections between them were both organisational and pattern seeking. I established the subsequent categories manually. The categories formed the basis for emerging themes/factors and concepts essential for substantiating established theories, hence offering in–depth and accurate interpretations in terms of, for instance, Expo students' perceptions of scientific investigations, the skills they believed they had developed, details of their performance regarding science process skills, their understanding of Life Sciences concepts, and experiences related to their projects. As I searched for these interpretations to describe these aspects, it was important that I revisited the transcriptions for information that would supplement the analysis where necessary.

Step four: It was important that I made a holistic analysis of the results from the interviews, questionnaires and the students' Expo reports. After all, Nieuwenhuis (2007) suggested that when using multiple data sources, checking the trustworthiness of the results is important. The holistic analysis was suitable to a holistic approach to qualitative data representation to be used. Indeed, Cohen *et al*. (2007) corroborated that such approach "will want to catch the wholeness of individuals and groups, and this may lead to…almost case study or story style of reporting with issues emerging as they arise during the narrative!" (p. 468). The following are two examples that illustrate holistic analysis of my results:

<u>Focus:</u>

- *Reasons* for the students' participation in Expos.
- Details of the students' performance regarding *process skills*.

Holistic analysis of the results:

- I triangulated pertinent information from, for instance, an Expo report's background/introduction with the results from the interview and the questionnaire questions namely, "What made you decide about taking part in the Expo?" and "Why did you enter the 2007 Expo competition?"
- Information related to, for example, the method section in an Expo report were triangulated with the results from the questionnaire and the interview questions, namely, "How did you manage your project from start to finish bearing in mind the important skills you learnt during the entire process?" and "What do you know about scientific processes that helped you in your project?"

The students' written responses to questionnaires and their Expo reports were the basis for content analyses of documents used.

Document analysis: Questionnaires and Expo reports

As referred to elsewhere (p. 68), students' performance in process skills and science concepts can be inferred from written responses or written work, such as a questionnaire and/or Expo report. In this study, analysis of the questionnaire provided me with a general idea of the skills the students thought they have used, and an idea of the state of the more challenging process skills they have used. The analysis also provided me with three major factors that shaped the students' participation in the Expos, and the students' perceptions of scientific investigations and/or science.

Thematic approach to analyses of data (without Nvivo) was used with the questionnaires, with the exception of challenging process skills (i.e., skills that students at pilot stage failed to understand). Studies by, for instance, So (2003) and Tytler (1992), provided theoretical basis prior to coding categories and the subsequent themes (i.e., factors) and trends identified from the written responses in the students' completed questionnaires. Indeed, Miles and Huberman (1994) indicated that the thematic approach to analyses of data could be applicable to information from questionnaires. They went further to say that a theoretical framework "can be used to study one case in depth, and then successive cases are examined to see whether the pattern found matches that in previous cases" (Miles & Huberman, 1994, p. 174). On the other hand, content analysis of the questionnaires was used in relation to the more challenging process skills. Content analysis was justifiable in relation to *the skills* (e.g., process skills) and Life Sciences knowledge in the students' work because it proved successful during the preliminary studies (Molefe, 2007, 2008). Content analysis is "a research technique for making replicable and valid inferences from texts (or other meaningful matter) to the contexts of their use" (Cohen *et al*., 2007, p. 475). The texts source may be from any source, for example, interview data (Flick, 2002), written scientific project report (Molefe, 2007; So, 2003), or both together with a questionnaire data (Molefe, 2008; Tytler, 1992). A content analysis technique used with the questionnaire was also used with the Expo reports (see pp. 87-88).

The purpose of the reports of the student was to elicit details about the relevant contents of the students' Expo reports (p. 81). In some projects, the reports provided even more insights regarding information pertinent to the students' experiences with the Expos. Researchers in qualitative research, such as Flick (2002) argue that although this method seems lucid, unambiguous and easier to handle compared to other methods of data analysis, it is embedded in quantitative methodology principles and as such its coding and categorising–oriented approach may lead to facile and superficial data whose schematic interpretation is divorced of the depths of the text (Flick, 2002). However, recent research in the field indicates that these claims may "misrepresent the flexibility of content analysis" (Cohen *et al*., 2007, p. 491) which may be evident in a more specialised design type – *qualitative* content analysis.

The basis for qualitative content analysis used to examine Expo students' performance regarding scientific skills (e.g., critical thinking skills, science process skills, etc.) and understanding of Life Sciences concepts in their reports included:

- The eleven prescribed *process skills* in the Natural Sciences (DoE, 2002).
- The prescribed students' competences in the development of knowledge in Life Sciences. Hence, the analyses were framed on the *Learning Outcomes* and *Assessment Standards*, and the *content areas* (DoE, 2003b).

Indeed, So (2003) utilised a similar approach with Hong Kong primary school students. The students' written reports of their science projects were used to examine details of their performance regarding science process skills and that of their understanding of scientific concepts. So's (2003) framework of analysis was based on:

- *Ideas* (e.g., sources of the students' ideas for their projects)
- *Design* (e.g., types of investigations used, manipulation of variables, etc.)
- *Interpretation* (e.g., gathering and making sense of data, representing data, analysing data and drawing conclusions).
- *Evaluation* (e.g., repeating tests and asking new questions).
- *Understanding and application* (e.g., understanding scientific concepts, and application in daily life).
- *Reflection* (e.g., the process and product of investigations).

I adapted a qualitative content analysis in the current study because it formed the basis for qualitative analysis of subsequent manageable and comprehensible proportions (with quality still intact) of large quantities of text in the completed questionnaires and reports of Expo students' projects – in order to elicit meaning in context and trends (Cohen *et al*., 2007). This implies that content analysis research provided me with a basis to learn about the Expo students by analysing and interpreting their recorded material regarding their in–depth investigations hence provide descriptive accounts of their development and demonstration of a wide array of scientific skills and Life Sciences concepts. I minimised the challenge of superficial findings by utilising the triangulation approach, which also played an important role in drawing conclusions on the students' acknowledged and interpreted experiences inherent to their projects.

In summary, the student interview data in Part 1 was instrumental in answering the first question. The questionnaire provided more complementary data (i.e., sources of inspiration, reasons for participation, sources of help/students' metacognitive abilities), with the Expo reports providing supplementary details, in some cases. The mentor interview data was also useful in providing supplementary details regarding the students' school environment pertinent to the Expos (i.e., science activities that might have sharpened the students' skills and knowledge at school).

In relation to the second question, the student interview data in Part 2 was instrumental in providing evidence of the students' understanding of the skills and knowledge, some of which were presented in details in their respective Expo reports. The questionnaire data enabled me address the more challenging process skills. The questionnaire data was also instrumental in providing evidence of the students' recognition and understanding of process skills they think they used, scientific investigations, and the associated scientific method.

The mentor interview data was instrumental in addressing the last question. The students' personal interviews, their Expo projects, and the questionnaire provided both complementary and supplementary data.

Chapter Summary

In this chapter I have outlined the methodological orientation of the study in which case study research approach was utilised. I presented the rationale behind the choice of Expos as the focus of the investigation. Then, I described the selected cases and sites, the ethical considerations that had to be taken into account, the details of the data collection strategies used, the nature of the produced data and the methodology adopted for processing and validating this data, and the data analysis procedure for each data collect strategy. The results and analyses of the present research study now follow in Chapter 4.

CHAPTER 4

RESULTS

Introduction

In the current chapter, I present the analyses of data on the development of scientific skills, such as process skills, problem–solving skills, scientific inquiry skills and critical thinking skills, and Life Sciences knowledge by Expo students. The students' biographies are also presented as essential components of the study. Hence, the chapter will be presented in two main sections.

In the first section – **Section A** – I address the Expo students' biographies pertinent to their projects. Evidence from (a) Part 1 (Chapter 3, p. 79) of the video–recorded interviews of Expo students, and (b) corroborative audio–recorded interviews of the Expo students' mentors will be used. The data from these two sets of interviews, together with complementary data from a questionnaire, and supplementary information from the students' project reports, will be used to identify factors that shaped the students' participation in the 2007 Expos. The factors will then be used to document the students' biographies. **Section B** is focused on the identification and descriptions of the Expo students' scientific skills and Life Sciences knowledge. Part 2 of the students' video–recorded interviews was used to address their scientific skills and knowledge. Evidence from Part 2 of the interviews, together with that from the questionnaire, and the information from the Expo reports, will be utilised to identify the scientific knowledge of these students inherent to their investigative projects and to describe their scientific skills.

As referred to in Table 3.1 (Chapter 3, p. 69), the participants, mentors and the schools that took part in this study were assigned pseudonyms. These pseudonyms and additional pseudonyms (footnote 4, p. 92) will be used when presenting the results in the abovementioned sections.

SECTION A: EXPO STUDENTS' BIOGRAPHIES PERTINENT TO THEIR PARTICIPATION IN EXPOS

In this section, I sequenced the case studies separately in order to portray real–life cameos of each Expo student's biography in relation to his/her Expo project. In each portrait, I selected and presented extended excerpts (now without "um"s, "eh"s, etc.) from the students' interviews in which the students were expressive, in order to portray the students' identified attributes and the nature of their experiences at the Expos. This was done to address the first research question – What factors shaped school students' participation in the ESKOM Expo competitions for young scientists?

Portraits of Expo students and insights from their mentors

A total of four key factors emerged from the analysis of collected data from five case studies of Expo participants' responses to their experience with the Expos. I was able to identify clusters and hierarchies of information that reflected certain common factors using NVivo software, which enabled me to organise the data from the five cases in the first place. The following are the identified factors that were reflected in each portrait:

- *Expo students' reasons for their participation in the Expos*: Personal goals that shaped the reasons for the Expo students' participation in the Expos.
- *The students' origins of ideas to investigate biological phenomena*: Expo students' own reflections of the Life Sciences–based experiences that prompted them to take altruistic actions through participation in the Expos.
- *Expo students' interest in science*: Experiences that aroused and maintained the students' interest in science (e.g., Life Sciences) and their subsequent participation in the Expos.
- *Insights from the Expo students' homes and the resources (i.e., expertise, information and/or materials) used*: Forms of support from the Expo students' families as well as the resources they utilised, which might have played a significant role in their Expo projects.

In addition to these factors, there were pertinent factors that were of great interest to me, which might be embedded in what Woolnough (1994) called effective science teaching in a wider sense. These pertinent factors encompassed: (a) mentors' reported classroom–based *methods and practices* that might have honed the students' skills and knowledge hence their success at the Expos; (b) the mentors' forms of *support* for their Expo students; and (c) the mentors' *views about the Expos' role* in their students' learning process. All these factors were instrumental in the description of the *schools' science learning environment* pertinent to the success of the Expo students.

The rationale behind all the identified factors mentioned above and the associated insights elicited was to portray their possible role in the students' development of scientific skills and knowledge. The results of the analysis of data on these students' skills and knowledge will be presented in Section B.

Alina

Alina[4] was a Grade 11 student from Western Cape High School. She was the sole participant in this study. She was one of the participants whose projects did not qualify for neither bronze nor silver at the 2007 Expo. During an interview, she asserted that her participation made her realise that she can work under pressure. She also discovered that she could compile a scientific report very well. Furthermore, she answered that she "learnt a lot about diabetes…like the aspects of it, and how people can get it and how they can control it".

Evidently, Expo was an important learning experience for her, hence I asked her about the reasons for participating in the Expo in the first place. She reported that their teacher told her to participate as she was a finalist in a participating grade (Grade 11) at her school. That was also how she got to know about the Expo. Though Alina was *told* to participate in the Expo, analysis of the interview showed that she was also motivated and inspired to participate. Firstly, she disclosed that her cousin – a BSc Honours student – motivated her to do the project. Her cousin was a reason she believed she could do the project; "a helper" who – based on evidence in her completed questionnaire – provided her with guidance in conducting the experiments. Analysis of her Expo report also revealed that her cousin played a major role in the choice of the research topic and the compilation of the scientific report. Secondly, she asserted that the main reason for her participation was to improve her Curriculum Vitae. Thirdly, Alina told me that she wanted to find out if she could "win further"

[4] The names of the participants, schools, organisations, and other people who provided assistance to the Expo students are pseudonyms.

with her project. She also wrote in her completed questionnaire: “I wanted to push my project to a higher level”. Analysis of the questionnaire further showed that she believed her participation would enable her to experience types of scientific questions investigated by her Expo peers and broaden her scope/“knowledge in science for one day”.

As our discussion progressed, I also asked Alina about the origin of her ideas for embarking in her project. Firstly, she revealed how she decided on what project to do: “I was thinking of something simple, but I could write a lot about, so, and diabetes is a very big problem around the world, so I thought I [should] do mine on blood glucose levels”. Then, she disclosed her personal motivation: “…there’s (sic) a lot of people that suffer from diabetes in my family, so that motivated me”. Her completed questionnaire provided a corroborative evidence of her motivation. Analysis of the questionnaire showed that the project helped her “to find a simpler way of preventing diabetes” as she conducted investigations on blood glucose levels in an attempt to understand main causes of this condition. She added: “This was my main inspiration and the fact that many people suffer from diabetes in my family”.

I also assumed that without sustained interest in science, Alina might have found a high quality project engendered qualities such as patience and perseverance difficult to sustain. After all, science projects and Fairs do not only develop students’ scientific skills and processes but also pertinent attitudes (Bencze, Bowen, & Arsenault, 2008). Consequently, it was imperative to find out if there was any evidence that she was interested in science and whether there was a direct correlation between her personal interest in science (e.g., Life Sciences) and her favourite subject(s), career inclination and presence of a family member in science field, such as medicine. Supplementary to these key determinants, important things Alina learnt in biology/science and areas of interest that shaped her investigation, biology/science as a subject at school, as well as the role of science in her life, were equally important areas of interest during our interview.

Analysis of the interview showed that Alina had a family member in science field – her cousin. When asked about her favourite subject at school, she thought her probable choice would be “maths…and bio”. She also answered about her potential career: “Something in the medical field…[I’m] not sure yet, but something in the medical field, maybe a doctor or something”. Alina also thought that science played a significant role in her life, and her observant eye recognised the need for coherent and logical science pedagogies: “It [science] plays a very big…role because we’ve to learn it at school at the moment; and…science teacher has to look at things at a more logical way”.

Despite some “disruption in class”, Alina asserted during the interview that biology at Western Cape High School was quite interesting and fascinating. She also found Physical Science very interesting. However, she held a conventional view that “bio is a subject that you don’t have to apply knowledge. You’ve to just learn it”. Nevertheless, she answered that the important things she liked when learning biology include the human body and how to label it. In addition to a reported Glucometer which “really fascinated” her, Alina was intrigued that “in the world diabetes is a major issue as a lot of people suffer from it”. Consequently, equipped with knowledge on human body and “the science” behind the Glucometer and how it is operated, she conducted in–depth investigation on diabetes to find answers on “why do people suffer from diabetes, and what causes their [blood glucose] levels to rise; what causes their levels to drop. What can be used to…prevent diabetes, what can be used to lower the blood glucose levels”.

Family help, particularly from parents, is encouraged in Science Fairs (Gifford & Wiygul, 1992; Kelly, 2000). Furthermore, supplementary to the assistance common to winning projects is the use of authentic equipment and materials (Neu, Baum, & Cooper, 2004). The involvement of Alina’s cousin in her projects suggested that her family might have contributed in shaping her participation in the Expo. Moreover, use of Glucometer suggested that she might have had access to equipment and materials. Hence, I asked Alina to tell me about the important people in her life and the characteristics of them that influenced her. Part 2 of the interview, which I used to elicit responses to the information she used for her projects and how she got it, provided me with pertinent additional insights on the kind of materials she utilised and their sources.

Alina informed me that at home she had access to some resources essential for accomplishing her investigation. The analysis of her Expo report showed that these included sterile blood lancets; alcohol swabs and cotton wool; carbohydrate and protein meals; and *Accu–Chek Active* equipment (e.g., indicator strips, Glucomonitor, etc.). Alina might have had access to these resources but analysis of the interview showed that she encountered a problem as well. It “was quite difficult” to obtain the Glucomonitor for measuring blood glucose levels of her subjects. The other resources she utilised included a computer with access to the Internet and an encyclopaedia. Analysis of the interview showed that pertinent information from the computer and the encyclopaedia was further supplemented with information from a library she visited and from her cousin.

Analysis of the interview showed that Alina had, in addition to the cousin's assistance (i.e., with relevant information and guidance in conducting the experiments), encouragement and support of her parents. For example, she reported that they always encouraged her (and her siblings), "If you do your best you'll always achieve what you want". The support from the parents (and other family members) was evident when she embarked upon her project. The family members became subjects of her investigation. Hence, it was no surprise that she considered her family (and friends) as important people in her life. Her family included a mother, father, two siblings and the cousin. Analysis of the interview showed that her father was a chartered accountant who worked as a project manager at a local university, while her mother looked after them.

Alina also shared with me her experiences of her school life during our conversation. She revealed her thoughts: "I think it's quite relaxed but sometimes very hectic when there're a **lot of projects**; but it's nice" (emphasis added). Hence, I contacted her mentor to validate her claims about school–based projects, and also to expand on pertinent scientific activities that were being implemented at Western Cape High School. The need to authenticate Alina's description and to discover more about the school was based on the premises that a school environment in which the overall Expo projects were presented and pursued might have played a significant role in Expo students' projects at Western Cape High School, especially by sharpening their interest.

During an interview with Mr. Paul – a mentor and a biology teacher at Western Cape High School (Table 3.1, p. 69) – I sought to enquire about: (a) the scientific activities implemented in science classes, and (b) the Expo programmes at the school. With these two aspects, I intended to verify, and where necessary, to elaborate on Alina's descriptions about the way they learnt science and/or biology at school and her claims about the Expos at school. It should be noted that some of Alina's responses were shallow. As a result, I decided to extract pertinent excerpts from Part 2 of her interview to supplement her responses.

Alina thought a "science teacher has to look at things at a more logical way". What was interesting about Alina's responses to the interview questions about learning science at school was that she verified the teaching orthodoxy that science teachers help shape students' interest in science. For Alina, Western Cape High School's standard of science, which she claimed was quite high, was determined by the quality of the teachers and behaviour of the students. She answered during the interview:

> OK, the bio at Western Cape High School, the bio section is quite interesting and the teacher is also quite good. He teaches very well so we always listen to him. Physics on the other hand is also very interesting, but the teacher isn't so good so we kinda like paying attention in class…but it's quite of high standard at Western Cape High School.

However, how was Biology actually *learnt* at Western Cape High School? Analysis of the interview in this regard suggested that Alina's responses were "tinted" with the conventional view that biology is merely a learning subject and therefore it is divorced from application of knowledge. She thought that learning biology at school was all about listening and paying attention which, according to her, "make work less to learn at home". Were her responses more or less a product of limited practical approach to learning science at Western Cape High School?

Mr. Paul shared his thoughts about Biology/Life Sciences with respect to the methods and practices of teaching that teachers implement at Western Cape High School. He answered: "I can't really say that the teaching is what does it". He explained that, in addition to nurturing the students' own initiative, which according to him is a preeminent life skill, what counts include motivating the students:

> I suppose really it comes down to motivating them…giving them feedback regularly, putting them through our own Science Fair first. I think it's very important, so that they've opportunity to be assessed…the outcomes that are used…we use the same rubric as for the Expos, so that they get feedback on how they are doing. Then, of course prizes are awarded. That's motivating. And, I think largely just encouraging them to, to really get the success going I think…

Mr. Paul also revealed that prior to the "Science Fair" at Western Cape High School, mentors – who were also these students' science teachers – made sure that their students had "theory of what the scientists do, how…they go about their work" (i.e., the theory around the "scientific method".[5]). However, the students' experiences of the type of investigations that best honed their scientific skills and knowledge were, as Mr. Paul put it, "a little bit limited" because the students were subjected to "one or two" of what he called "set pieces of [scientific] work" in which the teachers "set

[5] The "scientific method" has been used as a project guide for Expo students and therefore mirrors a project report. This explains why current Expo students have failed to recognise process skills embedded in it.

them [students] an experiment and they follow the procedures [and] the outcome very often is already known”. Nevertheless, Mr. Paul felt that even though the students were “not having to really use their own initiative” in these closed investigations, it was a necessary step before they experienced advanced form of inquiry common at the regional Expos. He also reasoned that the students had a chance to manipulate apparatus and equipment both in primary school and through some of the practical work completed at Western Cape High School, and that had honed their skills “to the situation where they get to…apply what they’ve actually learnt in a new situation [such as the Expo]”.

Mr. Paul also shared with me the support the school provided to the Expo students when they plan, conduct and prepare their projects for the Expos. From my discussions with him, it became evident that science teachers in Grades 9 and 11 at Western Cape High School were obliged to support the Expo students. All the teachers in these grades became the students’ mentors. The mentors themselves provided time in class to answer questions and disseminate information to the students on how to go about their projects. Then, the students were encouraged to use Internet to search for ideas that they might use to start their projects. And, the students obtained progress reports and advice on their projects from the mentors. Mr. Paul added:

> And, then of course the support comes later in the assessment when we conduct interviews with every learner, so they get to…particularly if they are going off to the Expo, they’ll get at least some or a little bit of feedback on their projects – how it goes – through a personal interview with one of the teachers or outside judges.

Moreover, the analysis of my interview with Mr. Paul showed that the support provided to Western Cape High School students was also in the form of the successful Expo participants from previous Expos. Mr. Paul provided an illustration. Apparently, two Grade 12 girls from the school who were 2007 Expo participants had their project awarded gold. Mr. Paul continued that “[the mentors] asked them to come and speak to the Grade 9s [in 2008] and just tell them about what it was like and the experience it was [at the Expos]”. It should be noted that these precedents were utilised as one of the strategies the school employed to make their students’ participation in the Expos a success, as we shall discover.

In order to elicit additional meaningful data that might shed more light on Western Cape High School previous successes at the Expos, I asked Mr. Paul to enlighten me about their school’s environment. This encompassed the organisation structures concerning the Expos they had in place at their school and the strategies the school implemented to make their students' participation in the Expos a success.

Analysis of the interview with Mr. Paul showed that at Western Cape High School, Expos were very much part of the school science curricula (i.e., Natural Sciences, Physical Sciences, and Life Sciences). Mr. Paul elaborated on this: "…basically we use Science Fair project as a substantial portion of the continuous assessment mark in grade 9 and grade 11 [– the two participating Grades]". Mr. Paul reported that doors were always open for other junior and senior grades who never participated. Based on my casual observation at the school in 2007 and at the 2007 regional Expo, the students were allowed to participate either in pairs or as individuals.

Mr. Paul further reported that at Western Cape High School they also have a Science Fair team. They met regularly early on in the Expo preparation process. Meanwhile, the students were expected to have decided on a topic and handed in a one–page interim report of what they planned to do a year before a regional Expo. They would then get feedback and advice on whether their projects were of acceptable standard, were suitable and which areas needed improvement.

As referred elsewhere (p. 96), science teachers who taught juniors in a particular year mentored the students. Similarly, the seniors were taken care of by Physical Sciences or Life Sciences teachers. Apart from mentoring their own classes, each teacher has a function or a portfolio in setting up the entire process (e.g., it could be setting up facilities, marking and assessment procedure, or taking charge of the public relations, etc. [Mr. Paul's examples]). The school also has Science Fairs (i.e., internal Expos) in which the students set up their projects for the public.

My conversation with Mr. Paul also included the role of Expos in students' learning. He shared with me his views about Expos and Science Fairs, as he illustrated his thoughts by using Life Sciences and Physical Sciences:

> To me…the big thing from a lot of scientific work in the Life Sciences particularly is it needs to be run over a significant period of time. Class work and even a small class project doesn't blend itself to…in Physical Science or Chemistry you can, in one lesson, you can set up a practical and you can learn quite a lot and you can write up a report on that. But, certainly with the Life Sciences, most Life Sciences studies have to extend over a period of at least several weeks or months to allow the plants to grow, the microorganisms to develop or whatever it is that's been studied. And, so really, I mean, that is what real Life Sciences's about. And, *the Expo, I think is really and Science Fairs already the only opportunity that learners see the progression of science and scientific investigation over a significant period of time* (emphasis added).

Mr. Paul also disclosed that he thought Expos provide a springboard for students "who can excel, and who can do well, and have the potential", to realise their dreams. He continued: "That's how I see it. I'll be quite interested in what other people'll see as the main role of Expo competitions".

From our discussions, it became evident that for Mr. Paul Expos play a major role in students' skills development at Western Cape High School. He elaborated that Expos firstly nurture students' presentation skills. He argued that without these skills, a well–researched piece of work may "come to nought". Secondly, Expos enable the students to hone their research skills. Once again he contended that without these skills, a "wonderful presentation" might amount to nothing. Thirdly, Expos enable students to interact with professionals in a scientific sphere. He illustrated that the professional may be a relative, friend or even their parents. These people, he continued, may be their teachers/mentors to them on a one–to–one basis. Fourthly, Expos enable the students develop essential skills associated with finding relevant background knowledge in Internet. And finally, Mr. Paul felt that Expos enable students to experience hands–on science in which they have opportunities to handle and manipulate authentic equipment and apparatus.

Apart from the abovementioned organisation structures and the role of Expos in students' learning, Mr. Paul also enlightened me about the strategies for success they implemented at Western Cape High School. Firstly, they had some forms of encouragement. Mr. Paul reported that, as a result of their annual Science Fairs, they have role models who, through what they could produce in the regional Expos, have proved useful in inspiring potential Expo students. He went further that "there's the public recognition that's offered to them [Expo students] as well" through these extra–curricular science activities – regional Expos and/or Science Fairs. He elaborated:

> Yes…I think that's very important, you know. They receive public acknowledgement for the work they've done…I think the fact that the Fair runs year after year means there is a model or precedent. Learners have already seen what other learners can produce. So, that in itself becomes a strategy.

Western Cape High School also has some incentives which include either a prize of about R300 or a merit certificate which, according to Mr. Paul, proved valuable for the students' "CV and when they [Expo students] apply for study or work opportunities too".

Secondly, analysis of the interview showed that the school had decided to implement new strategies to improve their success at the Expos. For instance, Mr. Paul felt that his Expo students needed good physical facilities to create their displays. He reported: "…we've got budget a year ahead for…the other physical facilities. I think it's very important to have good physical facilities to create a display…we gonna have to now budget and spent a little bit more". (It should be noted that 30% of Part B of the Expo scoring sheet is allocated for an Expo exhibition/project's display.) Also, during our discussion on the role of Expos in students' learning, Mr. Paul emphasised the need for his students to be articulate in their presentations (again, 20% of Part C of the Expo scoring sheet is allocated for oral communication) and meticulous in their research (i.e., an attribute emphasised in Part A of Expo scoring sheet). Furthermore, the fact that they had decided, in 2008, to start "priming" their students a year before the annual regional Expos suggests that they intended to ensure that the students have ample time, starting with the 2009 Expo, to prepare for the Expos after their Science Fairs which, according to Mr. Paul, would have to come earlier too.

Elizabeth

Elizabeth was a Grade 10 student from St. Peter's Grammar School. She made it known right from the beginning that she is "quite interested in biology" and it is her favourite subject. As we continued with our conversation, she also shared with me her experiences about the 2007 Expo in which her project was awarded a silver medal. The analysis of the interview showed that the experience provided her not only with an opportunity to learn about blood pressure, but also "everything that has got to do with" her project, all of which were the result of background information pertinent to her research: "I'd to get background information on everything I did. So, everything about blood pressure I learnt a lot". Elizabeth learnt some skills as well. These included time management and communication skills. She elaborated:

> …the teachers don't think, oh, so she has got an Expo, I can't give her homework, you know what I mean. You've to fit it into your daily life. So, I had to learn *time management*. And, also sort of *communication skills*, because before…I couldn't really. You know, I did do oral and stuff but this really helped me because you…convey your message over to so many people. That, it really helps you (emphases added).

Elizabeth expanded on her personal experience with the Expo. She thought that it provided a launch pad in which she could develop herself. For instance, she felt that her self–confidence improved. She reasoned during the interview: "…because you're so proud of your project then you want to convey it, you know what I mean. So, it's like it helps you with your confidence". She added that her participation also made her realise her potential: "And, also…you learn so much about your ability, like what you can actually do…"

Analysis of Elizabeth's completed questionnaire further showed that she had no personal reasons to participate in the 2007 Expo. When asked about the reasons behind her participation, the explanation was that Expo is part of their school's ethos. It is part of the science curriculum and, as such, all students "taking science [at St. Peter's Grammar School] must do it". She elaborated on this during the interview:

> OK, well…after the Expo at school, they judged the pupil. And, then they chose…I think a few participants that they thought their projects were good enough to go to this round. So, that's basically why I came here…It's compulsory to do Expo in Grade[s] 10 and 11. So, that's basically how I got to know [about] it, because all the pupils that do Expo…that do science have to do Expo.

Elizabeth might have had no personal reasons to participate in the Expo, but she was able to provide the basis of ideas pertinent to her participation in the Expos. Firstly, she asserted in the completed questionnaire that "[she has] always been interested in the area of medical science". Secondly, analyses of the questionnaire and of her Expo report revealed that her home–based experience with video games and a research on video games were instrumental in generating ideas for her project. She stated in her report that when her brother and his friends played video games, their moods changed. She explained the moods: "They would get irritated and angry when they lost". She recognised that the games had similar effects on her. Her heart would beat faster as well. Analyses of the report and the questionnaire also showed that she was aware that many people play video games or computer games in their spare time and she sought to find the games' effects on blood pressure. Thus, her interest in video and computer games and the effects they had on blood pressure, together with her interest in "the human body and its functions", proved to be a springboard for starting the project. In her Expo report she stated that her project would especially be informative for "people that already have conditions like Pre–hypertension or bordering on high blood pressure".

As referred to earlier, research on video games also had influence on her project. Evidence from her Expo report revealed that she wanted "to expand [on] it [the research]". She added: "Most research is done on violent video games and I wanted to see if racing video games would have similar effects". She also discovered contradiction in previous research and wanted to formulate her "own opinion and see if similar results were found in South Africa".

Our interview also led to the issues of interest in science. Analysis of the questionnaire showed that Elizabeth had a sustained interest in science. She proclaimed that the area of medical science always aroused her curiosity. Consequently, it was imperative to find out if there was a direct correlation between her personal interest in medical science and other determinants of her interest in science, such as a family member in science field. She had no family member in science field. Regardless, her choice of subjects was in tandem with her future career. Analysis of the interview showed that her desired future career provided her with an insight into the role of science in her life. She substantiated this: "One of the main…thing is that…it [science] [is] involved in a career I want to follow one day". She continued: "And, a career is a big part of your life…because that's what you gonna do when you grow up for your whole life. So, I think it has got a big impact in my life…" Elizabeth's responses shed more light on science and her future career. As stated elsewhere (p. 100), she thought she particularly loved biology. She asserted that she would like to go into medicine when she finished school. She added during the interview: "…firstly…my most important thing is [being] a general practitioner. And, then after that I would like to go into paediatrics".

Analysis of the interview revealed that despite her obvious interest in an area of biology – ecosystems – the human body particularly fascinated her: "I'm also interested in science in the ecosystems and…the environment. But my favourite is the human body". She had her reasons: "…it really helped [me] a lot with this project because we've done blood system and all that kind of stuff". Elizabeth also held conventional view about biology. She thought "it's more learning work" and theory–laden. She thought these mentioned characteristics of biology made the subject quite challenging. Nevertheless, she maintained that she loved biology because she enjoyed it and was interested in it. Hence, it was no surprise that her eagerness to seek explanations for the phenomenon she observed seemed to be intertwined with her drive to make a difference in other people's lives, especially their health, as is also evident from her love for a career in Paediatrics. She wrote in her Expo report: "My project informs people so that they can play video games in moderation and avoid the risk of endangering their health".

We also conversed about the role played by her family in shaping her participation in the Expo, as well as the resources she utilised. Elizabeth felt that, in addition to her teachers and friends, her family constituted the most important people in her life: "OK, important people? I've got quite a few, like all my family. I think it's quite important because…they support me, and they're always there for me". She loved her parents for their industrious nature. She thought that it was a trait that she "really appreciate[d], like, look up to" about them. She added: "…they really work very hard to…get me to what I want to be". In the interview she revealed that her father was self–employed, providing – according to Elizabeth – "a delivery service". Her mother was a swimming instructor. Elizabeth revealed that her mother "didn't go and study further after" her matriculation. According her, her mother "was more involved in sort of physical [education]…" She added: "…she teaches people to swim". Elizabeth's mother was particularly supportive. Elizabeth revealed that the contribution of her mother encompassed "locating tools for test", taking care of various arrangements and her transportation.

Analysis of Elizabeth's interview showed that she had resources at home for obtaining background information related to her investigation: "And, I have Internet at home, so that's how I got that [information on blood pressure and video games]. And, we also got [Microsoft] Encarta [Encyclopaedia, 2000] at home…" Furthermore, Elizabeth acknowledged in her written Expo report that she had other people who supported her in her endeavour. They assisted her with some level of expertise and/or resources essential to make her project a success. The expertise and/or resources included: (a) "help with analysing results and understanding concepts" from a local doctor; and (b) a book provided by a particular person titled – *Take the pressure off your heart* – which was "basically all about conditions…that include blood pressure and all that kind of stuff". During our conversation she also revealed that somebody lent her his home–based blood pressure monitor, which she "…used…to measure the blood pressure".

In regard to Elizabeth's experiences at St. Peter's Grammar School, she answered: "My school life? I really enjoy my school life". However, Elizabeth disclosed that despite the inviting environment at school, demanding schoolwork and commuting from home to school also proved strenuous:

> It's very busy at times, and lots of time you feel…under so much pressure to do all your work. But…I really enjoy the environment at school and everything. And, it does get a bit much with the bus because of…all that kind of travelling the whole time. But, I really enjoy my school...

When asked about learning science at St. Peter's Grammar School, Elizabeth thought it was a very good opportunity. Her perception of learning science at school was more focused on understanding biological concepts rather than the practical part of biology.

Her perception about biology was no surprise considering that she thought that biology is mostly theory–laden. She said of assimilation of biological concepts: "…it is difficult at times 'cause sometimes you didn't grasp concepts straight away, and you must carry on to the next chapter. But…once you've got it, it's so nice". In the light of Elizabeth's perception of learning science at school, it was essential that I sought to look for additional insights regarding the *schools' science learning environment* pertinent to the success of the students at the Expos (p. 92).

The students from the school were under the mentorship of Ms. Nicola who was also – as she described herself in her responses to my interview questions – a "senior science teacher" at the school. Analysis of Ms. Nicola's responses showed that she took an initiative to run the Expos at the school and that she had been in charge of the organisation of Expos. She wrote: "The other teachers help with the judging of our interior Expo, but do not enter any learners at present. If my learners need extra support or advice they will provide it". Ms. Nicola listed (she preferred to respond to the interview questions and the subsequent follow–up questions through e–mail) the following roles of Expos in the learning process of students at St. Peter's Grammar School, which shed a light as to why she took the initiative:

- I know that it prepares them for their projects at university.
- It gives them confidence in themselves.
- They learn from each other because they see what their friends are doing and gain experience.
- They are able to use the total scientific method.
- They often get to know other knowledgeable people.
- It sometimes motivates them to study in a Science field.
- It teaches them perseverance.

As referred to earlier, also important in this study was a portrayal of the students' science learning experience at St. Peter's Grammar School. Analyses of Elizabeth's interview revealed that "[they have] done lots of experiments at school", which according to Elizabeth were instrumental it the students' layout of the Expo projects. She illustrated:

> Like, first you get…your aim, and then your hypothesis, and then you must write down your method. And…then you record your results. And, then you like get it all together and compare it and analyse it and then you…do the conclusions.

In addition to the description of the practical side of science learning outlined above, Elizabeth shared with me how they particularly learnt biology at school. Her description also provided an insight regarding her perception of biology as a subject:

> [Biology]'s quite a learning subject, you know what I mean. It's not like science [which]'s more practical. Once you've got the concept you know how to do it. Biology, I usually in a class you listen quite well because you [have to] grasp so many extra things. And, then…when I go home I usually make summaries of the work I've done, and then I would study...

In the light of the above background, I asked Ms. Nicola about the science activities and Expo programmes at St. Peter's Grammar School. Analysis of her responses provided a portrayal of a school in which emphasis was on students' way of thinking as they acquired research experience intertwined with the scientific method (footnote 5, p. 96). Ms. Nicola reasoned that though the research work "is of course much shorter than the Expo research project…that does not matter as it is a way of thinking". The implementation of this approach, particularly at a lower grade (i.e., Grade 9) shows that it set the stage for more authentic investigations that might be experienced at the Expos by the senior grades (i.e., Grades 10 and 11).

Analysis of Ms. Nicola's responses also showed that teaching the students "to do experiments according to the scientific method" in rubric fashion was considered pivotal in sharpening their scientific skills and knowledge at the school. Ms. Nicola illustrated that a practical would be selected "from a book and they [students] have to put together their hypothesis, variables method apparatus etc and make it work on their own". She explained further that the students were expected to draw their own conclusions and discuss their findings with a teacher. The practical work had short research questions and the students were also encouraged to use Internet search for certain topics to come up with "interesting" explanations. The implication of this background on practical work practiced at St. Peter's Grammar School was that the school practiced "closed investigations". The sole differentiating factor, in an attempt to sharpen the students' educational outcomes, such as their scientific skills, through these investigations, was an emphasis on Internet utilisation as the students researched certain topics as part of their classwork.

The abovementioned approach to sharpening the students' scientific skills and knowledge seemed to work for St. Peter's Grammar School, based on a copy of the impressive results of their 18 students' performance in 2007 Expo, which was provided by Ms. Nicola. The school produced five gold medallists. The report also showed that two of the five students were awarded "special prizes". One of the two students was nominated to represent the Western Cape at national level. The school also produced six silver and three bronze medallists.

Now, when the participating grades had the research experience and were ready to embark on their Expo projects, Ms. Nicola reported that they would be supported in different ways. She asserted that the support would entail: (a) potential Expo students' motivation; (b) "packet of notes" for the students, which contained:

- topics to get them thinking;
- exposure to the standard judging sheet/rubric;
- notes on how to put a poster together;
- notes on a research report;
- encouragement to do "something practical that can be measured and placed in tables and on graphs"; and
- encouragement to seek advice from universities and research institutes.

Ms. Nicola went further to share with me the school's science learning environment in terms of the two key factors that might have determined students' academic achievement and their success at the Expos – the school's *organisational culture* and *management strategies*. Associated with these emphasised aspects, based on Ms. Nicola's responses, were pertinent school ethos, which included: (b) motivation and encouragement (i.e., in the form of prizes [e.g., school colours]) from teachers, although based on evidence from the interview's data, the ethos were masterminded by Ms. Nicola; and (a) high expectations in relation to the science projects (i.e., challenging students in the participating grades to meet the school ethos in relation to the Expos).

Ms. Nicola reported the grades that participate at St. Peter's Grammar School: "I teach Grade[s] 10, 11 and 12. I only enter Grade[s] 10 and 11 learners. All grades are actually involved, but I only enter the kids I teach. Grade 12 learners are too busy". She added that it was highly recommended that the students work as individuals, but they were allowed to decide whether they wanted to work as individuals or in collaboration with their peers.

Ms. Nicola's reports showed that as part of preparations for the regional Expo, it was a norm in St. Peter's Grammar School to organise a launch for an internal Expos. It should be noted again that the scientific method practiced at St. Peter's Grammar School provided the students with a way of thinking prior to tackling the more challenging Expo projects. Analysis of Ms. Nicola's report showed that right from the beginning she would explain to the students coming through to Grade 10 that they were going to take part in an Expo competition and that they "will have *one* [Science Expo/Fair] at school and that the best project will go through to the regional competition" (emphasis added).

Ms. Nicola's responses showed that she would give Grade 10 and 11 students a speech in which she would explain the preparation process and give them the essential motivation. Her speech encompassed sharing with the students her experiences of the Expos over the years, which included strategies of getting "the necessary information" for their projects. Ms. Nicola emphasised further that she would hand them rubrics as well as a long list of possible topics and information they might need. The students would also have access to previous projects that – based on Elizabeth's description of science activities at St. Peter's Grammar School (p. 104) – served as templates. A date would be given for the students to hand in their novel projects. The students would then be assured that doors were always open for them if they needed any further support.

Ms. Nicola might have shouldered most of the responsibilities associated with the Expos (pp. 104, 107). She maintained: "I organise our own Expo at school in the hall and organise judges. Some of these judges will be teachers from our school, old Physical Science students or researchers from the university or research institutes in Stellenbosch". She went further to elaborate that the judging process at St. Peter's Grammar School was exactly the same as for the regional Expo.

Ms. Nicola also reported on preparations for the regional and national Expos. According to her, the students whose projects had great potential would be invited to a classroom during a chosen afternoon to discuss the projects in terms of their "strong aspects and weak aspects". It would then be up to the students to use their discretion in making the necessary changes. Ms. Nicola corroborated: "It is their choice. If they are chosen to go to the nationals their projects are once again evaluated according to the critique they got. They can then improve if they wish to". Furthermore, Ms. Nicola reported that "if they [participating students] win a gold at the National Expo competition they get awarded school colours".

Felicia

Felicia was one of the three students (others were Gertrude and Henry) from Protea High School. She was in Grade 10. Analysis of the interview showed that the Expo competition offered her a stage "to gain confidence in speaking". Her quest for gaining confidence in speaking, and socialising, played a part in her participation, as we shall discover later.

Based on evidence from the interview, Expo participation made her aware that nothing was impossible if one set his/her own goals, believed in them, and made them a reality: "[I learnt that] if you put your mind to it, you can achieve anything". Analysis of the interview further showed that her project also provided her with valuable medicine–oriented knowledge ("medical aspects") that could be applied in everyday life. The "medical aspects" during her investigation made her aware that science's or medical science's findings are not conclusive because there are many influential factors involved when conducting an investigation on a biological phenomenon. Furthermore, the implication drawn from the interview was that her project equipped her with learning experiences of "other aspects" to medical aspects namely (a) scientific process in terms of sound planning, and (b) maturity – proficiency in sustaining an interest, alacrity to excel, persevere at one's own enterprise, and hence the production of high quality work. She answered: "…other aspects? If you wanna get somewhere, you gonna like strive for it; put an effort; plan everything. If something doesn't [work] the first time go back, re[do it]… like change things, do it again".

When asked about the reasons behind her participation in the Expo, analysis of Felicia's completed questionnaire showed that she felt that participation was compulsory because it was for her class mark. Nevertheless, she decided to "further" the project at the Expo because it was a "perfect opportunity" to share ideas and make new friends. During our conversation, she placed emphases on these aims: "to extend it [is] just generally what motivates me…[And] the *exact same thing*...learn about people…exchange ideas" (emphasis added). She added that she wanted to be experienced and to gain confidence in speaking as well.

Despite her emphasis in her written responses to the questionnaire that "it was a compulsory project", Felicia had a catalyst behind her involvement with the Expo, as research played a significant role in her participation. During the interview (Part 2) she revealed the root of her inspiration to pursue the Expo project: "…basically, it stems from the *Women's Health Initiative Study [WHIS]*, which I'd read at the beginning to get ideas". She added, "…you can see that a lot of stuff in that study's very inaccurate...if you actually analyse it". Her diary showed that it was because of this "inaccurate stuff" that she "decided to look at it [WHIS][6] more". Analysis of her Expo report indicated that the "stuff" included WHIS's controversial claim of certain risks of Hormone Replacement Therapy (HRT) (e.g., increased risk of heart disease, thrombosis and breast cancer) that, according to her, are not only insignificant in reality but also "seemed to override previous findings and opinions that HRT caused a decreased risk of heart disease as well as a reduction in osteoporosis fractures and menopausal symptoms". Consequently, Felicia believed that her project could contribute to spreading awareness and help to educate women in South Africa. Her successful Life Sciences–based investigative project went on to be among gold medal–winning projects at national level.

Our conversation led to the most interesting part of her involvement with the Expo – evidence of her sustained interest in science. During the interview, she disclosed that her father is a considerably experienced rheumatologist. He played a significant role in her project, as we shall discover later. Considering that she had a supportive family member in medicine/science, it was surprising that her favourite subject was history, albeit during the interview she disclosed that she wanted to do Physiology but that it was not offered at Protea High School. She also claimed that she had "absolutely no idea" about her future career.

What other aspects made Felicia different from the rest of the participants was that she did not study Life Sciences: She took Physical Sciences at Protea High School. However, she could share with me her views and perspectives about science in general. Analysis of the interview showed that she thought that the role of science in her life had something to do with "finding out how the world works", especially when integrated with history. She added – indicating enthusiasm for investigating scientific phenomena – "it's just interesting to see what works". This was evident in her Expo project in which she investigated an oncology–oriented problem in HRT usage patterns to seek explanations on the relationship between breast cancer and hormone usage patterns:

[6] WHI Study was published in July 17, 2002. Writing Group for the Women's Health Initiative Investigators noted relations between use of HRT products and strokes, heart attacks, and hormone related breast cancers.

> …I looked, I looked at general trends…HRT exposure, as far as mammograms go, the people who had an exposure to HRT and the people who had breast cancer both had mammograms more often compared to the other two groups. So, I always looked at the chance and then even with…'cause the whole point was to see whether HRT exposure did increase the breast cancer risk. So, I looked at people and then over the board like I think it was 70% of people [that] had HRT exposure. And…there was no actual difference between breast cancer from non–breast cancer group. So, basically it said…HRT – very common to use…didn't actually significantly increase your chance to breast cancer.

Analysis of the questionnaire showed that the support system Felicia had at home was in the form of "materials/resources" she needed to complete her Expo project. Hence, I asked her about her family and the resources she utilised to make the project a success. She did not hesitate when asked about the important people in her life. She answered during the interview: "Family, of course". Evidence from the interview showed that her mother was a teacher. "She did like special needs and everything. But, now she just generally teaches three and four years [sic] olds". On the other hand, her father – a rheumatologist who had been practicing for 14 years – specialised in "arthritis and joints and all that stuff". Analysis of the interview also showed that Felicia thought her older sister is one of her greatest role models. Hence, as evident in a diary attached to the Expo report, it was no surprise that Felicia had a brainstorming session with her, which subsequently led to a discussion on HRT.

Analysis of Felicia's Expo report revealed that she had the support of her family and some contacts concerning her project. Her family was part of the control group (i.e., people without breast cancer) in her study. Her father was also part of the discussions on HRT, and he assisted with handing out surveys, carrying out patient recruitment, as well as with data analyses on Excel and the collation of statistics and research information. During the interview, she disclosed that her mother assisted with transport. This was essential because she had contacts – "middlemen" – at one hospital in Cape Town whom she had to contact and/or meet for feedback. Analysis of her Expo report indicated that the "middlemen" were responsible for handing out her surveys. She had additional "middlemen" that helped with the surveys at hospitals and "beautician places". Analysis of the report also revealed forms of assistance from doctors that included carrying out patient recruitment, and assistance with relevant information and medical journals. Analysis of the interview provided a clue regarding the resources she obtained from the doctors' rooms. She collected "pamphlets…on menopause, [and] HRT" and journals which included – *Women's Health Initiative Study* – whose controversial (according to Felicia) breast cancer–HRT publication let to her investigation. Furthermore, analysis of Felicia's Expo report showed that she had consulted a professor from one of the South African universities and the "Ethics committee [of] SAMA [South African Medical Association]" for ethical considerations and for approval of her project to proceed. She also acknowledged that she used "advice and constructive criticism at Regionals in Cape Town [to prepare for the national Expo]". Analysis of the interview showed that Felicia also had access to the Internet, which was used to access information relevant to her investigation. Felicia also visited libraries. This provided an insight on why she claimed she used "all different dictionaries, encyclopaedias", books, and magazines on HRT for her project.

Felicia chuckled when asked about her school life. Analysis of the interview showed that a comfort she asserted she had at school might have been rooted in a friendship she cultivated with some of her academic peers. She thought that despite more school work, she now appreciated being at school: "I really enjoy school…you get [to] have your friends. And, even if you get all the work…it sets yourself up for your future. Now, I enjoy it". I also asked her about learning science at Protea High School. Analysis of the interview showed that she savoured learning science because their school had good science teachers who were flexible and accommodated her easy–going personality. She corroborated: "[Physical] Science? Mr. Daniel is brilliant! [So, there are] no problems with science. No, it's, it's not exac[tly]…it's not like very formal. So, you can chill and…it's…you still like do the academic aspects. So, it's balanced". Mr. Daniel was a Physical Science teacher and the Expo students' mentor at Protea High School (Table 3.1, p. 69).

Gertrude

Gertrude was a Grade 10 student at Protea High School as well. She called her highly successful project an "invention". She became a celebrated young scientist as a result of the distinctions awarded for excellence in Expo project at both national and international levels: She was awarded gold medals for her project at both national and international levels; won the ESKOM Best Female Award at the national Expo, and won first prize for excellent performance in Beijing, China, where she represented South Africa. During the interview, she described herself as a very determined person, reliable, responsible, and organised, with good time management skills.

Analysis of the interview showed that Gertrude's Expo project provided her with a lasting learning experience on scientific process, which encompassed the importance of sound planning, execution and presentation of investigations. She justified these important *aspects* as she elaborated on the valuable things learnt while carrying out her Expo project:

> You learn how to do research. Like in later in life like whenever you're in a university you always've to do some sort of research. You learn [about] how to put scientific process into action. You learn about the…your outcomes, your expected results, your method. You do know about how to write all those, and how to like get those across without leaving anything out like any important information like you can't leave out like something that's important in your method 'cause it leaves gaps and you need to know how to fill those gaps...

Analysis of her completed questionnaire indicated that the abovementioned aspects formed part of the reasons she asserted were behind her participation in the 2007 Expo, as we shall discover later.

During the interview, Gertrude also reflected on the most important things she learnt about herself in doing her successful Expo project. Firstly, she thought that the project "turned out to be something more than it could've been" – an "invention" rather than a mere school science project. Indeed, during the interview she maintained that "it is not just a low project that you did on the side. It's something that you'll always remember". Then, she mentioned personal attribute(s) that might have enabled her to immerse herself in her Expo project: "…you learn that you're determined person and that nothing will stand on your way, and…you need to make sacrifices in life to do something well".

When asked during the interview about the reasons behind her participation in the 2007 Expo, Gertrude felt that at Protea High School they "kind of didn't really have a choice". Participation was compulsory because "everybody who does science and biology…has to do a project, which is marked for actual school marks". She continued: "So, we get…doing it like we do it at the Western Cape Expo". This obligatory nature about the Expo was also the reason they knew about it at school. Nevertheless, Gertrude said that she would have participated in the Expo even if it was optional: "But, I still would've done it even though we didn't have the choice". The commonality elicited out of the analyses of the completed questionnaire and the interview data was that she would have participated because Expos open a lot of opportunities. Her perception about Expos was best outlined in the questionnaire. Firstly, she made it clear that her participation had something to do with her passion for science and her longing to "invent something with a great meaning to today's society". Then, she expanded on Expo–related opportunities provided by her Expo participation:

> Expo opens opportunities to study in areas of life, knowledge on how to put through a scientific investigation and experience for university. It opens you up to be creative and use your brain. It gives you something to be proud about and to know that you are capable of achieving things.

Gertrude also shared with me the origin of her ideas to participate in the Expo, which was twofold. Firstly, analysis of the questionnaire showed that the project marks – by virtue of being part of students' term mark at Protea High School – were a linchpin in her motivation to participate in the Expo. As a self–proclaimed determined person, she was insistent to getting "a very good mark…knowing of the opportunities that lie ahead". She felt she was a "straight–A student", and I discovered that she thought, with great marks at school, that she would have an opportunity to study at a leading institution overseas. Secondly, her Expo report revealed what was probably her inspiration to pursue the project – Fundus[7] of a diabetic grandfather (Figure 4.1, p. 167). She reported:

> This research project was stimulated by a recent Fundus photograph of my grandfather, who has diabetes. This photograph caused me to ask the question as to whether all Fundi look the same. I approached an optometrist who owns a Fundus camera to show me different Fundus photographs. This *sparked* the idea of using the Fundus to identify a person (emphasis added).

Analysis of the interview provided supplementary information on Gertrude's origin of her ideas with respect to Fundi photos. The information also shed a light on how she decided what project to do. She explained:

> Well, it didn't start of like [I'm] just going…I'm gonna use fundus to identify people with…It has to come up with some reason for doing that. So, what actually happens is I'll actually gonna use these fundus photographs to see if I can diagnose different stages of a condition such as…AIDS, diabetes, because these photographs actually can show different conditions. And, they're basically are something…to check [and] make sure that the person really does have it…so I was gonna do that. And, then I just started taking like different measurements and stuff of the fundus, of the pictures, 'cause I started with just the sample of ten. And, I found that it was working, and I thought that I'd try it out and see if I got different numbers for…each picture. And, I did a 1000, and I got different numbers for everyone.

We also conversed about science and her interest in it. During the interview, I discovered that Gertrude has a parent she considerably adored in the science field (e.g., medicine) – her father who practices optometry. Analysis of the interview showed that he was very influential to her; a reason why it came as a surprise to me that Gertrude intended to pursue engineering rather than medicine in the future. She asserted: "I wanna study civil engineering". Her assertion motivated me to revisit the

[7] Fundus is an internal surface of an eye located opposite the lens, and it encompasses, *inter alia*, the retina, optic disc, and fovea. Its photos have been used to diagnose pathological conditions of the rear of the eye.

issue (i.e., her preference of engineering over medicine), and she disclosed that there is still an option for her to go into medicine: “Biology’s a good subject to have. And, there’s still an option for me to go into medicine”. Medicine was evidently a second choice for her because she thought “it’ll…take a prolonged time to study medicine and…there are a lot of sacrifices involved”. Despite her sceptical thoughts about medicine, Biology – apart from Mathematics – was a subject she enjoyed the most.

As referred to earlier (p. 111), Gertrude’s *science* project made her a celebrated young scientist at both provincial and national level. Hence, I sought to find out what her views were regarding science in general. She acknowledged that science played an important role in her life. Her views about science were rooted in evolution theory: “[science] is very important ‘cause it shows understanding on how…the whole world is put together…understanding of…the world, like how things…evolve and develop”. Gertrude also revealed her perception of science (i.e., Physical Sciences) compared to biology (i.e., Life Sciences). She thought science was all about composition of matter (e.g., different chemicals that constitute a tap [her example]) while biology was about ecosystem and how human body systems work together. Gertrude also held orthodox views about science and biology. She thought when studying these subjects, relating what was learnt in the classroom to the real life situations merely applied to science. She thought science as a subject was “definitely more [about] understanding the work”, which involved application to different situations, whereas biology, although it was “a lot of understanding as well”, was basically learning, for example, lists of abiotic factors (her example) and knowing the exact definitions of processes such as diffusion in cells (another illustration she provided). According to her, “understanding how…things work like diffusion of cells and…the definition for it…the exact one” are what made biology quite a challenging subject.

Gertrude went on to tell me about an important area of science she liked, which she learnt at Protea High School, namely human anatomy:

> I think important things are like the cell, I mean I’ll never forget about the cell, learning plant tissue, animal tissue, *how the human body works*, the different systems, I mean I think we’ve about 12 different systems in our bodies (emphasis added).

It was no surprise, therefore, that “using the [human] body to…identify people” (i.e., applying physiological type of Biometrics[8]) became what Gertrude reported as her area of interest she explored with her Expo project. Her in–depth investigation was

[8] Biometrics encompasses methods of identifying people based upon, *inter alia*, their intrinsic traits (e.g., a person’s physical or behavioural characteristics).

based on "the future identification" of people based upon observation of unique Fundi of their eyes. She thought that hers was the best method of identifying a person compared to other methods. She felt that compared to the other methods – which she categorised as "Contact Biometric Technologies" (e.g., fingerprint) and "Contactless Biometric Technologies" (e.g., voice recognition) – hers (also an example of contactless Biometrics) was more reliable because "people cannot change the internal characteristics of the eye" and, most importantly, it could be utilised "to identify lost children".

Gertrude also provided me with insight regarding her family and the resources she utilised to make her Expo project a success. When asked about important people in her life during the interview, she smiled with pride as she mentioned her "inspirational" father who was a university graduate. She thought that he was a clever and determined person who knew her abilities and was supportive of her and her younger brother: "Oh! He's like determination and he is like knowledge of my abilities…He'll support me with whatever I want to do, which I know that I've got his support…he's teaching my brother Grade 8…he is very like inspirational".

Apart from her supportive father and access to other resources essential for accomplishing her investigation, analysis of her Expo report showed that, most importantly, she had access to a rare and expensive Topcon Fundus camera (the "Trc Nw100" model worth about R140 000.00). She told me that it was "borrowed…from [a] very nice man" – also a doctor practicing optometry. The Expo report revealed that the doctor provided her with optometry expertise as well. She disclosed: "I approached an Optometrist who owns a Fundus camera to show me different Fundus photographs". According to Gertrude, the consultation included information about the most stable areas of the eye. Indeed, during the interview Gertrude disclosed that the doctor became pivotal in "the research on the actual stable point in the eye".

The other resources Gertrude used in her Expo project included the Internet. She elaborated: "I used the Internet to research other methods of biometric identification as well…like present methods and emerging methods". Her Expo report showed that she also had a laptop (Figure 4.1, p. 167) she utilised for a "Paint" program for her sampled photographs. The laptop also played a major role in her PowerPoint presentations: "And, also what I did is I made a presentation, like a PowerPoint presentation…for people who didn't only want to read". Furthermore, she used

Human & Ocular Anatomy, which according to her was authored by Freddo (2001), for additional background information connected with the eye.

When asked about her school life, Gertrude thought her school "is very much an academic school". Evidence from the interview showed that her assertion was based on the premises that in Protea High School students are provided with "more than a basic education [in Expos, which hone their creativity and talents]". Furthermore, the school has best human resources and facilities: "I think the teachers are good. We've very highly qualified teachers. In certain subjects we even have doctors in that subject they teach us…I think our school buildings [are] really nice like the classrooms they've put a lot of effort into it". Gertrude had also referred me to Protea High School's contemporarily designed teaching aids, such as smart boards which, according to her, were utilised for PowerPoint–based lessons both for science and biology. Hence, it was no surprise that she pointed out that, with these kind of resources and facilities, "…there's no way they're [the school] gonna…turn anybody down". In order to support her assertion, she reported that the school produces most "A"s at the end of Grade 12.

Henry

Henry was the only male participant in this study. He completes the trio from Protea High School. He had knack for adventure, and strong curiosity about living organisms. Furthermore, he was keen to spend his time learning novel ideas related to Physical Sciences. He proclaimed:

> …I like doing everything, OK. If there's something new, I like doing it. So, basically I'm always doing new things…I like all sorts of things. I like sciences, especially…physics…I like spending my time…learning things like that…I like analysing living things.

His experience with the 2007 Expo competition provided him with insights concerning the extent of his capabilities and the nature of Expo competitions. He discovered that embarking on this endeavour (i.e., Expo participation) required commitment and "…working hard. Like really, really hard…basically like dedication…'cause…there weren't really many short cuts". He added: "…with this Expo it was kind of like…really hard…I thought I was lazy. So, I proved myself wrong…I can do hard work".

Henry also shared with me the reasons for his involvement of the Expos. Firstly, he validated his mentor's (as we shall discover later) and other two participants' assertions that the competition had been part of Protea High School's science curriculum. He thought that the school utilised it as a project. He added: "And, if they like your project, then [they] put it forward into the actual Expo competition [the ESKOM Expo competition]. So…it's been advised by the school". The implication of his assertions about Expos at the school was that he was obliged to participate. This was also how he ended up knowing about the 2007 Expo. Secondly, Henry felt that although this competition was somehow compulsory, he also had personal reasons to participate in it. He wrote in his questionnaire: "I got selected to enter by my school and decided it would look good on my CV [Curriculum Vitae]". He also disclosed that he was always fond of "doing these types of things [Expos]". After all, he proclaimed that he has "been doing it [participating in the Expo] for the past three years". He added: "It's…nice motivation, you know, do hard work…it's also nice to participate in things like that".

Henry thought that what inspired him to start his project was his experience with allergies. Analysis of his Expo report showed that he also became aware that allergic diseases continue to have significant impact on his age group. His past experience with allergies was illustrated during the interview:

> Well…I used to have a lot of allergies. And…at the school a lot of my friends…have asthma. So…when we're playing sport with them, sometimes they can't play. So…it's quite a significant thing…in my school, so I decided…let's investigate it.

In his Expo report, he stated the significance of his study to our everyday life. He wrote that "allergies can have a debilitating affect on the academic performance". As a result, he thought that his project would provide people with a broader knowledge about allergies, particularly for 14–18 year–old high school students. He added that it was his hope that the "study will create a greater awareness of this problem and how to approach it".

Analysis of the interview showed that Henry got this sense of compassion and an inspiration to embark on a project based on medical sciences from two older brothers. The brothers had careers in medicine – one of the brothers was a paramedic and the other a dentist. According to Henry, the latter "[the dentist] was always studying something medical and always used to read…textbooks". The dentist's proclivity for books became influential to Henry.

As our conversation progressed, I sought to find more evidence about Henry's possible sustained interest in science. Despite his earlier claim (mentioned at beginning of this case) about his penchant for science, especially Physical Sciences, Henry thought that Information Technology (IT) was his favourite subject. Nevertheless, his perspectives and feelings about science further showed that he actually had interest in it. When asked about the role of science in his life, he thought it was one of his favourite subjects. Like the brother who practised dentistry, he was "always…reading books about it [science]". He maintained during the interview that he loved learning about new things in science. Henry also shared with me what proved to be another commonality between himself and his brother. He disclosed during the interview: "…medicine. That's [what I want to do]…yah". With this choice of career, it was imperative to find out about his views regarding biology/Life Sciences at school.

Henry held the conventional view about biology: It is detail–oriented and it is basically a learning subject that one could easily pass. He thought these characteristic features about biology make it a great subject, yet challenging. He elaborated:

> …it's not like a hard subject…You just got to learn…you can get a good mark…if you really want to – that's what I like about it…So, if you put in effort you'll get a good mark…[About its challenges], I'll take just the quantity of an information that you've to know…so when you are learning…tissues like plants and animal tissues, just like the quantity of things that you've to know. So…just every detail…of what happens inside the cell…why it affects…the respiration. You know, all types of things. It's, it's mainly the quantity...

Henry went further to share with me the most important things he liked when learning biology. His focus was on respiration in a multicellular organism (e.g., man): "The most important things I learnt was probably about…respiration. Just how the body…takes an air and actually utilises it…and breaks down carbohydrates…How it actually produces energy".

When asked about an area of interest he explored for his Expo project, he said: "I'd say…the effect of stress on allergies. It was definitely [the] one…" This area of interest coupled with his experiences (i.e., incidences of allergies and asthma, and his influential siblings and parents), formed a springboard on which Henry could investigate and seek further explanations on the relationship between the incidences of allergies and "family history, location, stress" or any other contributory factors to the students' allergies, and the extent to which that was the case. The project was awarded a bronze medal at regional level.

Our conversation also led to issues around the role played by his family in his project and the resources he utilised to make his project a success. Henry emphasised in the first place that his parents and his siblings were the important people in his life. His mother was an artist. He added during the interview: "So, she…teaches a bit, but she has no like real…constant work…she did a degree of Fine Arts" at one of the South African universities. His father was a practicing attorney, who had studied at the local university.

Henry had sufficient support at home regarding the project. His father, in particular, played a major role in what Expo project to do. Henry's father advised him to do a project on a phenomenon that he observed and was quite familiar with. Henry substantiated his father's influence:

> …my father…suggested…looking into something…that you see quite a lot. So, I thought…about it. And, I decided…allergies. You see it everyday…you don't actually notice it, but it's really a pretty big thing…people can't do certain things…it's quite limiting.

Henry also acknowledged in his Expo report that his father contributed also by "proofreading some of the data". In the report, Henry showed that his mother also offered a helping hand in the project. He acknowledged that she assisted him with "[transport] to the various departments, medical libraries and photocopy shops". According to Henry, she was also instrumental in constructing the layout of the project. Furthermore, Henry's brother – the dental surgeon – "kind of assisted [as well]".

Both the interview and the Expo report also showed that Henry had access to other people who had high levels of expertise in the area of his study, namely, two Professors – one from a local university's Lung Institute and the other from a local children's hospital. They assisted him with resources essential to make his study a success. The following were the resources recommended and/or made available by the Professor from the Institute: "medical journals that were specifically about allergies…pamphlets about each allergy…books and websites". Furthermore, Henry revealed that he had "discussions" with the Professor from children's hospital, which dealt with "allergies specifically in children and teenagers". The Professor's assistance also included editing a "copy of the survey" Henry used in the Expo project. Henry also acknowledged in his Expo report that he used some scholarly magazines in *Current Allergy and Clinical Immunology*, and a relevant research poster, which the Professor from the Institute had co–authored.

Henry then gave an account of his experiences at school. Firstly, he disclosed a casual attitude he normally had, particularly during examinations: "…usually I['d] just…start a day before the exam…get like a…mark that was…good but…if I worked hard I could've got a good one". Then, he pointed out that his school life was now good because his experience with the 2007 Expo competition changed his perception regarding his approach to his schoolwork. Now that he had decided "to put in effort…study pretty hard" and also made an effort to work "a lot lately", he felt that there was progress: "…school's being pretty good at the moment…I mean it's improved lately".

As stated elsewhere (pp. 91-92), I intended to analyse some factors that would help me outline the schools' science learning environment pertinent to the success of the Expo students. It should be noted again that unlike Felicia, Gertrude and Henry took biology as one of the subjects at Protea High School. And, the current study is framed on Life Sciences. Consequently, the insights on actual and detailed science learning environment at Protea High School were elicited from their (i.e., Gertrude and Henry) interviews' data *than* from Felicia's. Hence, I present the collective responses of these young scientists (i.e., Gertrude and Henry) about their school and the corroborative evidence and/or additional insights from their mentor – Mr. Daniel. The following were the main factors that were explored to draw insights on Protea High School's learning environment: (a) learning *science* at school, and (b) how the students went about learning *biology* at school.

According to Gertrude, biology (Life Sciences) and science (Physical Sciences) were learnt the same way. PowerPoint–based notes on smart boards and utilisation of a textbook and tutorials dominated learning of science and/or biology at the school:

> …we also've a textbook, which is similar to what's on the PowerPoint just in a lot less detailed [as the book's material] and without like experiments and stuff to understand. And, we basically stick between those two and…the teacher'll stand up in every lesson and give us an explanation…and make sure like everybody understand it, otherwise he'll either give them tutorial…during break or after school, or he'll explain it during the class.

For Henry, science at Protea High School was of a high standard. His perception of the quality of science teaching at the school was based on the competence of Mr. Daniel. He elaborated on science at the school during the interview:

> …science in my school…is pretty good. I'm sure you know our Mr. Daniel. He wrote our textbook. So, it's nice to have a teacher that actually…knows…what the whole syllabus is. He actually wrote it, so it's nice…you feel assisted. Unfortunately Mr. Daniel doesn't teach me. But…it's still…good to have him there and he runs the department. So, what we're learning is…pretty good and…it's top [and of] good

> standard…

Analysis of our interview also revealed Henry's conventional view about biology, which was reinforced in the way he thought he learnt science at school: "…what I do is I…take notes during class. And, then…I type them up at home [to] make summaries…'cause it's…that type of subject…it's [basically about] learning".

Mr. Daniel's subsequent description of science learning environment at Protea High School seemed to add rather than corroborate the descriptions of Gertrude and Henry. During my interview with him, he portrayed an impressive practical approach to teaching science at the school. It should be noted that evidence drawn from the interview showed that at Protea High School, starting in middle school, science students rigorously learnt the scientific method as part of the school's science curriculum. Bochinski (2004, p. 9) argued that "the basic procedure involved in a science project is modeled on a process called the **scientific method**" (emphasis in the original). Likewise, at Protea High School students were encouraged to "model" their projects on this method. Hence, both middle and high school students had opportunity to experience the "extension" (i.e., from classroom to beyond classroom) of the scientific method in Expo projects. Indeed, Felicia's Expo report showed that her project was modeled on the scientific method: She wrote: "Science Expo 2007 Extended Scientific Method".

Mr. Daniel elaborated on the methods and practices of teaching implemented by Protea High School teachers in Natural Science, Life Sciences, and Physical Sciences. Firstly, Mr. Daniel revealed the approach they use in classrooms: "…it's kind of developmental…constructivist theory type of approach that we are using…from the educational…methodological point of view". Mr. Daniel added that the students were honed in making experiment–bound observations and drawing conclusions from them. Secondly, Mr. Daniel maintained that the teachers cultivated excellence and refused to accept mediocrity from the students right from the start. The subsequent outcomes of the teachers' efforts, as Mr. Daniel put it, were "incredibly good examinations results on tests and so forth". Mr. Daniel continued:

> And, all of these impacts on Expo. Because all of these's setting a kind of ethos for Expo – *high experimentation* and a *high expectations*. And, the combination of those two, I think, is probably what makes them…do well at the Expo…(emphases added).

According to Mr. Daniel, these two emphasised basic principles, though intimidating at times to some students, worked amazingly well for all students because the teachers were prepared to "hold their hands" to ensure that they were able to cope. The *support* – "holding students' hands" – was extended to the Expos.

Analysis of the interview showed that Grade 10s – the participating grade – had access to the best exemplars of previous award–winning projects, and were enlightened by previous participants on how to do a project and set it up. The teachers would also provide the Expo students with "a little booklet" containing expectations and relevant information about Expo projects. Most importantly, they had access to the standard Expo judging sheet used, for example, at the national level. Mr. Daniel made it clear that the students did the projects themselves: "It's their project. It's for them to do". The teachers' basic duties encompassed giving the students feedback after a week and "advice as to how they can perhaps improve what they are doing". According to Mr. Daniel, this kind of facilitation process normally take a next step as time nears the regional Expo, with the students allowed to have one–on–one consultation with the teachers to get advice during breaks.

We also conversed about Protea High School's science learning environment in relation to the Expo participation–related organisation structures they had in place and the strategies the school implemented to make students' participation in the Expos a success. Mr. Daniel reported that the school put special attention to Expos more than to any other extramural activity because "there is this whole kind of…culture of Expo…being special [at the school], and they [students]'re going to have to try doing well in it". Mr. Daniel emphasised that, science teachers, by utilising methods and practices that worked over the years; the school, with its associated organisation structures that encompassed an internal Expo, prepare students to do well at Expos. He continued: "And…we are in that school, and we don't have to do it as well if [we] didn't do it well". For Mr. Daniel, "Protea is, and it is the best Expo school in Cape Town". In his words, "the results prove it". He had a copy of the results of their 20 students' performance in the 2008 Expo to validate his statement. In that year (2008), the school produced eight gold (seven of which were nominated for top awards in their respective categories), three silver, and five bronze medallists. It should be noted that Protea High School participants in that Expo were competing, in some cases, with Grade 11 students from other schools. Consequently, the school's results were impressive.

Mr. Daniel corroborated Henry and Gertrude's reports that Expos were meant for Grade 10s at Protea High School. He emphasised that the doors were always open for other senior grades who never participated. What was interesting about Protea High School students were the reasons they were selected to participate as individuals in the Expos. Firstly, Mr. Daniel disclosed that the school research findings revealed “that the quality is not necessarily better when two [i.e., a pair] work [together]”. Secondly, as Mr. Daniel put it, “there is always one person riding on the back of the other” in the Expo–bound collaboration. Even more interesting was the school’s rationale for the participating grade (i.e., Grade 10s). Mr. Daniel disclosed: “We felt that perhaps psychologically…these children are coming [from middle school] into the school and they’ll prove themselves”.

Analysis of the interview showed that subsequent to the students’ annual arrival from the middle school was a launch of Expo projects prior to an internal Expo and regional Expo. This normally involved all science teachers (i.e., two in Physical Sciences and two in Life Sciences) who ensured that the students started their Expo projects early (i.e., as early as February) and were given the support (p. 122) they needed. As a norm, four weeks after the launch the students were expected to have decided on a topic and handed in a one–page outline of what they planned to do. The students would then get feedback and advice (within a week) on whether their projects were of acceptable standard, were suitable and which areas needed improvement.

Mr. Daniel pointed out that as time nears the internal Expo, the facilitation process takes the next level – the students are allowed to have one–on–one consultation with the teachers to get advice during breaks. He also talked about assistance from other knowledgeable people. He pointed out that the students were also encouraged to seek help and advice from universities and were advised to “always to acknowledge whatever help they’ve been given, and to be careful in what they do”. This excerpt explains why Expo students from Protea High School were able to acknowledge their sources (Chapter 5, p. 225). Furthermore, Mr. Daniel acknowledged that the students also obtained support from their homes: “Obviously they’ll get help at home from parents to some extend”. Such support from home is normally extended to an annual “gala evening” (in May) which Mr. Daniel disclosed that the school “make a big fuss about”. Parents, in particular, quest speakers, and other schools are normally invited to see the students’ Expo exhibitions.

The students usually have “three to four months” to work on their Expo projects prior to the internal Expo held in May. The teachers would then perform the judging process according to the standard guidelines stipulated in the Cape Town Expo and National Expo. For instance, as stated elsewhere (p. 122), the students were provided with the standard Expo judging sheet and the marking sheet so that they could prepare their projects accordingly. 50% in Part A of Expo's scoring sheet is allocated for the projects' level of investigation and creativity. Therefore, as Mr. Daniel put it, each student was expected to do his/her best to produce "a topic at a high level of investigation" and make his/her poster "as colourful and appealing as possible", so as to cover every point in the targeted block in Part A. The internal Expo judging process was normally completed over a week during school time. Mr. Daniel emphasised: "We take them seriously…in judging, OK?" He maintained that the students had to come out of class on two occasions to have a 15–minutes interview with two teachers who were usually not their own class teachers. Mr. Daniel pointed out that it was a strenuous activity in which the teachers spent their free times (e.g., during free periods, break after school, sometimes before school, etc. [Mr. Daniel's examples]) to judge the students' work. They marked the students' work, prepared certificates and wrote comments on them that they participated in the Expo.

Mr. Daniel went further to share with me his views about Expo's role in students' learning. He thought it is "huge". He elaborated that:

- Expos enable students experience "high level of science in the process of doing their own projects". According to him, this may occur in advanced laboratories where the students may learn a particular procedure, testing and analysing using, for instance, spectroscopy.
- Expos may enable students experience advanced research first–hand. This may include: (a) negotiating access (e.g., the project might require one to write letters to organisations and meet research ethics); (b) preparing data gathering instruments (e.g., questionnaires), and (c) doing the research itself. Mr. Daniel provided Felicia's work as an exemplar to verify the statements in (a), (b) and (c).
- Expos may enable students to interact with professionals such as, for example, universities professors for advanced laboratory work.
- Expos may provide students with opportunities – especially for those who do very well – to reach the pinnacle of their work in school science and, in the process, become celebrated young scientists (Mr. Daniel's provided exemplar was Gertrude's work).
- Expos may enable students to experience science competitions at the highest level (i.e., international Expos).

- Expos, at regional, national, and international levels, may enable students meet other students of their own kind from other schools and from other cultures.

Mr. Daniel concluded that for Expo students, “all of those things [listed above] come together”.

SECTION B: OVERVIEW OF EXPO STUDENTS’ SCIENTIFIC SKILLS AND LIFE SCIENCES KNOWLEDGE

In this section, I draw from the South African science curricula (i.e., Life Sciences and Natural Sciences) and So’s (2003) ideas to address the educational outcomes – scientific skills and Life Sciences knowledge. The focus on the abovementioned educational outcomes was based on the Life Sciences curriculum (see DoE, 2003b) emphasis that scientific skills are best developed within the context for an expanding framework of knowledge. Expos provide such a context. The scientific skills encompass the introductory process skills stipulated in the Natural Sciences, as well as the experimental and data–handling skills prescribed in the Life Sciences (Table 1.2, p. 13). It should be noted that the link between the students’ actual educational outcomes, as reflected in the results of the study, and the theoretically informed definitions of these educational outcomes will be presented and discussed in the next chapter – Chapter 5.

I arranged the case studies separately once more in order to explore and analyse development of Expo students’ scientific skills in articulation with their abilities to utilise them to interpret and use Life Sciences concepts in explaining phenomena. It should be noted that the results regarding the scientific skills and Life Sciences knowledge were solely based on the analyses of the participants’ interviews, the written project reports and the completed questionnaires.

As stated elsewhere (Chapter 3, p. 77), the students had to complete a questionnaire. I formulated one question to find out what made them think they could accomplish their Expo projects. Furthermore, I also inquired about: (a) the *skills* they believed they might have learnt during the entire Expo participation process (i.e., as they managed their projects from start to finish), and (b) what their projects informed them about *science/scientific investigations*. During the interviews, I also inquired about the overall *challenges* they felt they have encountered when doing their projects.

My intention was to use the results from the students' thoughts about their competencies in completing Expo projects, their results from (a) and (b), and the challenges they encountered as an introductory part of each case study. I assumed that the results might also shed a light on what could be expected on the students' subsequent results on, for example, the development of the process skills. Hence, the results on the process skills and the students' competences and content areas in development of Life Sciences knowledge will form the main part of the five case studies presented below.

Alina

When asked about what made her think she could do the project in the questionnaire, Alina disclosed two main determining factors, which also provided supplementary information regarding insights from home and the resources utilised. The factors included her cousin's guidance and technology that was at her disposal. She elaborated:

> *I had a helper [cousin] that showed me how to go about doing the experiment*. Diabetes is a big concept and there are many aspects of diabetes that could be addressed. Apart from the information and the variety of concepts, testing blood glucose levels is quite an easy topic and a process that is to go about doing [it]. *With the **technology** we have today it was easy to do bar graphs and tables in a simple format* (emphases added).

Analysis of the interview showed that the technology she mentioned in the excerpt above included a computer: "…the project was quite easy to do because I did it on a *computer* and like bar graphs and line graphs are a programme on the X Microsoft Excel, so it was easy to use…easy to do" (emphasis added).

Despite the above assertions, Alina encountered some challenges related to her research and access to the sophisticated equipment she needed. She revealed during the interview:

> The most diffic[ult], I think researching[9] the background information because you're given a lot of information and choosing the right information to help you understand the project is quite vital. And, another quite…was quite difficult was the Glucokit, getting the Glucomonitor.

As referred to earlier (p. 125), Expo students were expected to draw from their experiences with Expo projects to reflect on scientific investigations. Such investigations may be categorised as fair testing and comparing, classifying and

[9] "Researching"/ "research" term actually implied information gathering.

identifying, pattern seeking, exploring, investigating models, and making things or developing systems (Watson, Goldsworthy, & Wood-Robinson, 1999). Analysis of the interview revealed that Alina's investigation involved "developing appropriate procedures to manipulate, observe, measure or control a number of variables" (Watson *et al*., 1999, p. 103), namely blood glucose levels, fasting, food intake, and exercise. Consequently, Alina's scientific investigation was categorised as fair testing and comparison. Analysis of the questionnaire revealed that Alina's reflections on scientific investigations were based on the importance of the process of investigation and a project's report. She thought "carrying out an investigation properly according to scientific report gives you remarkably accurate results under one condition that variables are controlled". According to Alina, the scientific method (footnote 5, p. 96) plays a major role in simplifying "the way of gathering information and coming up with the conclusion". Her thoughts regarding investigations might explain why the scientific method and the scientific report were predominant in her description of conducting investigation and planning scientific investigation respectively, as we shall discover later.

Science process skills

Alina made an attempt to report the skills she learnt during the project in her written questionnaire. Analysis of the questionnaire showed that for her, "the important skills that had to be there in the beginning was understanding the scientific report and how you go about doing the process". According to her, it was important to understand "this process" as it formed the basis for one's new scientific information and key concepts. She elaborated on "the process":

> The first part of the process, Aim [which] is the main question asked and then you build your project on the key concepts [namely] Apparatus, Method, Results & Discussion and Conclusion. I used this process as a guideline to which I based my project on (emphasis in the original).

Thus, for Alina, "the actual scientific report" comprised the aim, apparatus, method, results, discussion and conclusion. Mastering both the scientific report and the process of compiling it (i.e., the scientific method) were perceived as the important skills learnt when investigating diabetes.

Evidently, Alina did not incorporate the *actual activities* that she executed when investigating diabetes (e.g., science process skills, such as **planning scientific investigation** at the beginning and/or **communicating science information** she accumulated at the end) in this introduction of the skills she learnt. This shortcoming explains why, for Alina, skills used in executing a particular investigation were considered as merely abilities in compiling an impeccable scientific report, as well as understanding the scientific method. Moreover, in my opinion, the scientific report mirrors the scientific method (footnote 5). Hence, it was no surprise that she was not able to distinguish between, for example, the aim of the study (part of the report) and the main question of her study (part of the scientific method).

On the other hand, Alina was able to identify biological phenomenon to be tested. She noticed that many people in the world (including her family) suffer from diabetes. Analysis of the interview revealed that she sought “to test the blood glucose levels in various subjects [family members] and compare them” in quest of ways and means of regulating blood glucose levels associated with diabetes so as to help diabetic family members. The vivid account of test–based observations and comparisons she performed hence, how she made an attempt to develop the **observing and comparing** skills will be drawn from the report, the questionnaire, and the interview.

Alina was able to observe time. For example, her observations involved noting the precise time before testing blood glucose levels of diabetics and non–diabetics (i.e., after fasting 10 hours overnight; 30 minutes after a protein and carbohydrates breakfast; and 2 hours after a meal and mild exercise for 1 hour during the interval). Moreover, she was able to determine concentrations of blood glucose. A glucose monitor she utilised provided her with precise and quantified blood glucose concentrations. For instance, Type II diabetic’s blood glucose level that read 1.4 mMol/L. The implication is that the development of what Rule (1992) referred to as quantitative observations were at the forefront in her project. Her quantitative observations also imply that the development of skills included her ability to read a sophisticated scientific instrument she utilised – *Accu–Chek Active*, an blood glucose monitor/Glucometer. It should also be noted that she calculated averages essential in documenting graphs–based patterns so that “the results from the test group was [sic] compared to that of a Type I and Type II diabetic”. The ability to make and use quantitative observations and the associated use of the Glucometer were fundamental to Alina understanding diabetes.

Alina acknowledged that she encountered challenges related to the accuracy of her observations. She elaborated:

> …it was quite hard to be accurate because there's [sic] different people with different ages and some probably ate different potions of food and some probably walked more, so there's [sic] quite a lot of variables that'd to be taken into consideration.

However, analysis of her Expo report showed that Alina had proficiency in observing that:

1) a) "Carbohydrate–rich food have the greatest effect on blood glucose levels [as] there was an increase in blood glucose levels following food consumption".
   b) "Exercise decreases blood glucose levels".
   c) Fasting also resulted in low glucose levels.

In short, Alina was able to note that, unlike exercise and fasting, food intake increased blood glucose levels.

2) "Exercise had a profound effect on the blood glucose levels of diabetic patients". She illustrated: "In Type II diabetes the glucose level (post-meal with exercise) was 1.9mMol/L lower than that without exercise". Alina also illustrated that the glucose concentrations in the Type I diabetics were reduced by exercise to 1.4 mMol/L.

In summary, Alina was able to note the considerable difference in blood glucose levels in diabetics due to exercise.

3) "[The results of her experiments] were similar to what the information [from the Internet] say[s]". This implies that she was able to note that her experimental results were corresponding with the background information she researched.

Alina's quantitative observations synchronised with her attempts to develop her **measuring** skills. Nevertheless, I noticed that her responses to the interview questions were very short and therefore did not reflect a comprehensive account of the quantitative measurements made. Consequently, I decided to extract pertinent information from various parts of the interview (e.g., Part 2) and, where necessary, from her written Expo report to supplement the limited information from the interviews.

As referred to previously (p. 128), Alina had proficiency in measuring quantities of the subjects' blood glucose concentrations in millimoles per litre using appropriate apparatus in Glucometer. Analysis of the interview also showed that she thought "all [the tests] depend[ed] on time". Analysis of the Expo report showed that the time was "monitored accurately". Consequently, she was able to manipulate a watch to measure time in – based on evidence in the Expo report – both hours and minutes.

Alina might have been aware of, for instance, the importance of accuracy in monitoring time. However, she had misconceptions regarding measuring. For example, she thought *accuracy* and *precision* in measurements are about *controlling variables*. The interview–based evidence showed that she thought accuracy and precision were associated with trying "to control the variables…see that people…walked the same [distance] and ate the same amount of food".

The numerical measurements made had to be recorded. Alina was able to develop her proficiency in recording information associated with the measurements she made. The forms[10] of recording information she utilised were also found in the forms she used to represent data or communicate her science information. Indeed, Alina's reasons for her choices regarding certain forms of recording data were inclined to data representation. Furthermore, So (2003) description of representing data encompassed recording of information and data. Similarly, the descriptions of Alina's proficiency in **recording information** and **communicating science information** are presented concurrently.

Students may be better at working with tables than graphs (Beaumont–Walters & Soyibo, 2001). The analysis of Alina's Expo report showed that she was able to select a suitable table format in order to record and represent science information associated with quantities of each subjects' blood glucose levels in a given period of time. Indeed, she thought the "simple methods of communicating were tables" because from them one could easily recognise the different blood glucose levels. Furthermore, she was able to utilise bar graphs and line graphs for recording data. She thought that "the bar graph was the best" form of recording her information. Analysis of the interview showed that her thoughts were based on the premises that "it was quite easy to compare where it [concentration] rose [and] where it dropped [with the bar graphs]". She also thought that the line graph "was also quite accurate…but…you can't really see the difference as with the bar graph". The analysis of the interview also showed that certain forms of recording information were left out due to their limited accuracy and inability to show trends over time. For example, she answered that she did not to use pie charts because they were challenging and "not so accurate

[10] DoE (2002) uses *forms* in place of *ways/means* of representing and recording data and information.

and you can’t really distinguish the differences [in blood glucose concentrations over time]”.

It should be noted that Alina’s exhibition involved a report and a poster. Hence, she presented her work in written forms, which included prose text in her formal Expo report and the poster. The graphs (i.e., colourful charts) were also part of the mathematical and pictorial forms (see Colvill & Pattie, 2003) representing her science information, which also encompassed the tables of information and photographs. Alina elaborated on the colourful graphs in relation to the representation of her information. She thought the graphs, by virtue of being “more visual”, were “to grab attention” of the fellow Expo participants, the public, and the judges. She continued, as she also introduced the photos: “And the graphs were used to help people distinguish [the differences in blood glucose concentrations]; and a lot of visual pictures were put there to help them see how I went about doing the experiment”. Evidence from the interview showed that the bar graph was the finest way of communicating her information: “But the bar graph was a more sophisticated way but it was actually quite important aspect of this project because it helps you to distinguish easily the differences”.

In order to organise her recorded results (e.g., in the abovementioned table and the bar chart) and discuss her findings in her report systematically, Alina engaged in **sorting and classifying** her subjects as well. She wrote in her questionnaire: “The Glucometer, my 5 normal subjects, 1 diabetic (Type I) and another type II diabetic were my scientific items [that I sorted and classified]”. According to Alina, these items[11] “played an important role in carrying out the investigation”. The excerpt also explains why, in addition to the subjects she used in the development of her sorting and classifying skills, she included the Glucometer.

In terms of the subjects, analysis of her Expo report showed how she developed her classification skills through grouping the subjects in order to understand the relationship between them in relation to blood glucose levels. She selected a suitable system in table format and named them “subjects 1”, “subjects 2”, “subjects 3”, “subjects 4” and “subject 5”. The subjects were further grouped into “normal” and “diabetes” in the chart, with the latter represented as “Type I” and “Type II”.

[11] DoE (2002) presumes that sorting and classifying apply only to *items/scientific items*.

Analysis of Alina's interview showed that deciding on her own rules for classifying her subjects was easy: "There wasn't really anything challenging because they didn't have diabetes – the five subjects…because of their blood glucose levels you could see that, and Type II…we knew that he was diabetic and Type I".

Alina also made an attempt to create meaning and structure out of the data on diabetes and blood glucose levels – **interpreting information**. According to So (2003), details of students' performance on this skill should encompass:

(a) *Gathering and making sense of data* (i.e., use of scientific equipment; systematic gathering of data; making empirical observations, and translating them into usable data). It should be noted that interpreting information also involves "knowing how to get information from a book [and other relevant sources]" (DoE, 2002, p. 14). Therefore, a question was also asked to inquire about how the students obtained their background information.
(b) *Data representation* (i.e., recording and presenting information and data).
(c) *Analysing data and drawing conclusions* (i.e., type of investigation used, reasonable conclusions and suggestions made, and/or acceptable scientific explanations made, etc.).

The analysis of the interview showed that Alina was able to gather information relevant to her scientific investigation. She reported that "[she] used the internet and encyclopaedia [to search for the information]". She answered that she was aware that "there's a lot of information, so you have to look for the right things". Her cousin's information (and that from the library) was also part of "a lot of information" she accumulated. Analysis of the interview showed that the information was "the background about glucose levels and diabetes". According to her, the background information helped her understand what she did and to come up with her conclusion. It is important that students are aware of dangers of plagiarism when learning through science projects (So, 2003). Alina was able to acknowledge sources of help in, for example, her cousin.

Students' development of "skills in using equipment" constitutes gathering and making sense of data (So, 2003, p. 195). As referred to previously (p. 128) sophisticated equipment was utilised to measure and/or gather systematic data on blood glucose concentration over various given periods of time. In addition to a watch, which was not mentioned in the Expo report, the equipment included the

Accu–Chek Active equipment (e.g., blood glucose monitor, indicator strips, etc.) and other materials, namely, sterile blood lancets, alcohol swabs, and cotton wool. Her Expo report showed photos she used to: (a) illustrate to the people (e.g., peers, public and judges) components of the unique *Accu–Chek Active* equipment; and (b) to provide lucid description of how the *Accu–Chek Active* equipment was utilised in pictorial form.

Furthermore, analysis of Alina's Expo report showed that she was able to make sense of the data she had collected. For instance, the use of *Accu–Chek Active* equipment was coupled with hands–on observations. The result was the functional data that was ready to be interpreted. The functional data – her quantified concentrations – was the result of empirical observations rooted from systematic steps which involved noting the indicator strips and the subsequent monitor's readings according to the blood glucose concentrations of each subject. With the steps accomplished, her investigation enabled her to subsequently compare and discuss her data.

It was evident that Alina's ability to compare and discuss her data was rooted to appropriate data representation (p. 130). For instance, use of tables and graphs to provide clear, compact and concise information about the concentrations' varying quantities and trends. During the interview, Alina went further to support her data representation choices: "…the bar graphs, tables and the line graph helped to…set the information up and it also helped me to distinguish easily what it was…what was there". It should be noted again that she was aware that including the photos would provide the most effective way of presenting the important part of her investigation process – use of *Accu–Chek Active* equipment.

Alina also had to analyse her data to reach conclusions. As referred to elsewhere (p. 127), Alina's investigation predisposed her to carry out fair tests and perform some comparisons. As a result, she made an attempt to analyse blood glucose levels of her subjects. She answered during the interview:

> It [the information] was very accurate and I could see the differences in the diabetes levels. And, looking at the information in a table and bar graph[s] helps you to distinguish quickly where it rose where it dropped and come up with a conclusion.

Analysis of her Expo report showed that she was able to manipulate variables to ensure fair testing, and observe and compare trends regarding blood glucose levels of the subjects. The outcome of fair testing and the associated observations was a very short yet rational conclusion and a suggestion. For instance, in her Expo report she was able to conclude based on her principal findings (i.e., that of high levels of blood glucose of all subjects following food consumption and low levels following exercise [and overnight fasting]), "that exercise is effective in reducing blood sugar level". Hence, she suggested that, "exercise can be used as a natural way of reducing blood glucose levels in diabetic patients". She discussed that, consequently, diabetes might be contained through a lifestyle that encompasses "an effective diet and regular exercise". Analysis of the report showed that she thought, with this natural way (e.g., regular exercise), people may reduce their dependence on insulin and "may be able to obtain better function of the muscles and organs [as well]".

Alina's interpretation of information was also instrumental in her proficiency in **predicting**. After all, present trends or previously known information (drawn through interpreting information) form the basis for students' estimations or forecasts of future observations (Chapter 5, p. 244). From the analysis of the questionnaire, it was found that "estimations regarding the rise and fall in blood glucose levels according to fasting, eating and exercising state were made". Knowledge gained from observed patterns in research in the Internet material provided the basis for the estimations. The patterns also contained a table presenting the conversions of blood glucose levels' conversions and interpretation. She answered:

> This [the prediction] was based on the information gathered from the Internet; it gave a table of expectations. So my estimations were based on the table describing conversions of blood glucose levels and interpretation.

At the same time, the analysis of the questionnaire showed that Alina had proficiency in making a testable assumption of a relationship between factors (i.e., effect of exercise on blood glucose levels in diabetics and non–diabetics), and the subsequent explanation (using prior knowledge) for that relationship (DoE, 2002). According to the evidence in her questionnaire, the following were some of the tentative generalisations, which were subjected to testing through experiments:

- "…blood glucose levels will drop when exercise is done" and "after a night's sleep".
- "…after a meal the glucose level will rise".

In short, Alina's testable assumptions were that exercise and overnight fasting would cause blood glucose levels of the subjects to drop while food intake will cause positive change in the levels after 30 and 120 minutes. Analysis of the questionnaire showed that she had proficiency in **hypothesising** because she was able to utilise "the information gathered from the Internet" to provide reasons for her predictions. For example, analysis of the report showed that she was able to correlate the rise in blood glucose levels with metabolic processes resulting in glucose production: "…30 minutes after a meal the glucose levels will rise and [after] 120 minutes post meal it would rise even more *as it is enough time for the digestive enzymes to digest the food which will result in a higher glucose level*" (emphasis added). She was also able to reason that the levels will be low before breakfast "because no meal would have been taken then [overnight]". Though she did not state what would be the cause of the levels' drop during exercise, analysis of her Expo project (specifically her conclusion) revealed that she thought "*exercising decreases blood glucose levels by utilizing the glucose in circulation*" (emphasis added).

Shuttleworth (2004) argued that "the precursor to a hypothesis is a research problem, usually framed as a question" (para. 3). Hence, it was also essential that Expo students were able to think of "scientifically testable" questions that can be asked about a situation (DoE, 2002, p. 14). The fact that "in the world diabetes is a major issue as a lot of people suffer from it" prompted Alina into **raising questions about the situation**. Analysis of the interview indicated that the following were the questions she was able to formulate, which guided her investigation in which she aimed "to test the effects of fasting, food intake and exercise on blood glucose levels in normal subjects and patients with Type I and Type II diabetes":

- Why do people suffer from diabetes?
- What causes their [blood glucose] levels to rise?
- What causes their levels to drop?
- What can be used to prevent diabetes?
- What can be used to lower the blood glucose levels?

Evidently, her questions were broad statements that had to be reworded to make them scientifically testable (e.g., that seek to find correlation between variables under investigation). Alina thought by testing her subjects she could ensure that her questions were scientifically testable: "Like I said…testing my 5 subjects, type I and type II and that helped me".

The interview with Alina also shed light on her knowledge of **planning science investigation**. According to DoE (2002), planning science investigations entails identifying and controlling variables that matter in the problem or question. Students should also know which evidence needs to be collected to answer the question. They should be able to identify sophisticated equipment, materials, and methods, knowing how to improve the accuracy and validity of the measurements. They should also ensure that there are no errors or omissions.

It should be noted again that Alina designed fair tests. Analyses of her written questionnaire showed that she was not able to report one the most important components of planning scientific investigations – defining a problem. However, she was aware that in fair testing variables had to be identified and controlled: “The time and eating had to be monitored so [that] results would appear as accurate as possible. A lot of variables had to be controlled in order to achieve the results we did and in order to match [my] assumptions”. This was expected, as her Expo report had shown that she had proficiency in noting “variables to be controlled” (i.e., daily rations of food [her example]) and those to be tested/measured (i.e., blood glucose levels for specific periods of time [her example]) and how to observe and measure the variables. Evidence from the interview also authenticated her identified variables and the instrument to measure them. Regardless of her misconceptions in relation to precision and accuracy (p. 130), she also knew how to improve the accuracy and validity of the measurements. The description of her proficiency in conducting the investigation below provides insights on her plans in relation to errors or omissions.

Alina’s shortcoming with regard to the defined problem of her study made me revisit the problem. As referred to elsewhere (p. 127), she regarded the scientific report and the scientific method as the principal components of an investigation. It was thus no surprise that she thought the actual activities that should be executed at planning stage when investigating diabetes include *understanding* the scientific report. According to her, the scientific report should be a template for “remarkably accurate results” when planning an investigation. Indeed, the interview showed that the scientific report and the associated “process” (i.e., aim and apparatus) were her template in which “the main aspect” of her investigation was “to test the blood glucose levels” of normal and diabetic subjects and compare them. In order to do that she had to research background knowledge on blood glucose levels as well. She continued:

> …and I came up with my aim to test, to test the blood glucose levels in various subjects and compare them, and I can use my apparatus, which was the Glucometer…so without the Glucometer I wouldn’t be able do it, and that’s…and then I got my discussion and conclusion.

Most importantly, the scientific method was another template in Alina's plan. She reasoned in her questionnaire: "The *scientific method* simplifies the way of gathering information and coming up with the conclusion…" (emphasis added). However, her knowledge of the scientific method was limited. This was evident in her inability to recognise that the scientific method entails a problem or a research question (Watson & James, 2004). According to DoE (2002), such problem/question is pivotal in planning an investigation, and Watson and James (2004) showed that it encompasses skills such as, observing and communicating.

Alina's own thoughts of an investigation (p. 127) resurfaced as she described how she executed her investigations (**conducting the investigations**). It should be noted that Alina should have followed procedures thoroughly for the collection and recording of observations and her data. For instance, she should have "[manipulated variables] while controlling interfering variables, measuring the variables, recording data, interpreting data to make findings, and reporting in qualitative and quantitative terms" (DoE, 2002, p. 14). Alina thought that "testing the peoples' blood glucose level[s]…was the [main] practical part of it [conducting the investigation]". Analysis of the questionnaire showed that for her the remarkably accurate results mentioned under planning scientific investigation could be achieved "under one condition that *variables are controlled*" (emphasis added). The implication of her statement was that she was aware of the reasons for taking care of variables – obtaining results that were trustworthy.

I also interviewed Alina, in order to authenticate the components of conducting the investigations (i.e., controlling variables and measuring quantities). Firstly, she expanded on the issue of fair testing:

> …it all depended on time. So, to keep the variables controlled I'd to watch the time so that I wouldn't…lose…to be accurate I watched time all the time. And their eating – you'd to watch that, everybody ate the same proportion. And exercising – some shouldn't exercise too much or too little, so I watched that by timing them.

Then, analysis of the interview indicated that she was also able to take care of extraneous variables that might have negatively influenced the outcomes of her Expo project. The analysis of the interview showed that she was aware that she had "to ensure that everything is clean, no bacteria". She wore gloves prior to testing the subjects' blood.

Life Sciences knowledge

Tables 4.1a and 4.1b below present summarised descriptions of the knowledge that the analyses of Alina's three sets of data (i.e., data from the interview, the Expo report and the questionnaire) showed she had developed in her investigation on blood glucose levels. The analyses of Alina's case showed that the process of the Expo investigation and the scientific skills she developed formed the basis for the development of her scientific understandings of diabetes.

The analyses of Alina's case and the other four cases showed little or no information on the students' development of knowledge and skills stipulated in the Life Sciences' Learning Outcome 3 (LO3). Consequently, only information related to LO1 and LO2 is presented in the overall five cases.

Each Learning Outcome has Assessments Standards (ASs), that is, the minimum requirements expected of a student in order to progress to the next grade. The Assessment Standards in turn specify knowledge, skills, values and understanding students are expected to achieve in each grade. The last column (i.e., comments) provides analyses of the students' achievement of a given standard for a given grade.

Table 4.1a

Alina's developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 1: Scientific Inquiry and Problem–solving Skills (for Grade 11)

Assessment Standard (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Identifying and questioning phenomena and planning an investigation	Generating and questioning "hypotheses based on identified phenomena for situations involving more than one variable" (DoE, 2003b, p. 17) – for Grade 12	Alina's Expo report showed that she had proficiency in noting that diabetes is a major problem not only in the world but also in her family. She was aware that diabetes is due to changes in blood glucose levels. The interview showed that she was, therefore, able to hypothesise that changes in blood glucose levels could be linked, for example, to exercise and fasting.	Alina was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 11 students.

Table 4.1a continued

Assessment Standard (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Identifying and questioning phenomena and planning an investigation	Designing "tests and/or surveys to investigate these variables" (DoE, 2003b, p. 17) – for Grade 12	Alina was also able to design tests to find the correlation between blood glucose levels (in the normal subjects and the diabetics [e.g., Type I and Type II diabetics]) and the three circumstances namely fasting, food intake and exercise. Her scientific investigation was a combination of fair testing and comparison. Therefore, she was expected to address the issue of "fair" tests as well, which she did.	Alina was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 11 students.
	Evaluating "the experimental design" (DoE, 2003b, p. 17) – for Grade 12	Alina claimed she was satisfied with the outcomes of her Expo project. Nevertheless, her evaluation showed that she felt her projects should have encompassed investigating simple yet sufficient alternatives to exercise – "the natural way of depleting blood glucose levels" – to help diabetics.	
2. Conducting an investigation by collecting and manipulating data	Systematically and accurately collect data using selected instruments and/or techniques (DoE, 2003b)	Firstly, her interview showed that she was familiar with a sophisticated equipment she used to collect data – Glucometer: "OK, working with the Glucometer really fascinated me and how the science behind it, and how it works, so that was very interesting". Her Expo report showed that she had a setup in which the participants' blood glucose levels for the following periods were tested using the equipment: ▪ After fasting for 10 hours overnight; ▪ 30 minutes after a protein and carbohydrate breakfast; ▪ 2 hours after breakfast; and ▪ 2 hours after a meal and with mild exercise (walking 1 hour during that interval). The interview also revealed that prior to the recording process of the data on blood glucose levels of each of the subjects, she "worked out" the levels' averages. The report showed that the levels were systematically recorded in tabular format. Despite addressing "fair" testing, Alina identified limitations of her techniques: …it was quite hard to be accurate because there's different people with different ages and some probably ate different potions of food and some probably walked more, so there's quite a lot of variables that'd to be taken into consideration.	Alina was able to meet the AS for Grade 11.

Table 4.1a continued

Assessment Standard (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Conducting an investigation by collecting and manipulating data	Selection of "a type of display that communicates the data effectively" (DoE, 2003b, p. 21)	Alina summarised and displayed in a poster all the results and plans to communicate her science information in mathematical and pictorial forms as part of the Expo exhibition. The exhibition also encompassed her report to communicate the new knowledge developed for the specific audience now in details.	Alina was able to meet the AS for Grade 11.
3. Analysing, synthesising, evaluating data and communicating findings.	Comparing data and constructing meaning to "explain findings" (DoE, 2003b, p. 23)	She could compare data between diabetics and non–diabetics, and diabetics themselves to draw meaning from line graphs and the chart to explain her results. For example, overall, the subjects' food intake resulted in rise in the subjects' levels. She had proficiency in explaining that the rise was due to metabolic processes whose end products included glucose production. Likewise, the levels' drop during, *inter alia*, exercise were explained to be due to utilisation of the glucose in circulation. She also recognised that the effect of exercise on diabetics is even great – a reason why she recommended it to them.	Alina was able to meet the AS for Grade 11.
	Drawing conclusions and recognising "inconsistencies in the data" (DoE, 2003b, p. 23)	Alina was able to conclude that "exercise is effective in reducing blood sugar level". Nevertheless, her conclusions did not incorporate possible inconsistencies in the data as the result of certain factors in 2. (e.g., technique's limitations).	

Table 4.1a continued

Assessment Standard (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
3. Analysing, synthesising, evaluating data and communicating findings.	Assess the value of the experimental process and communicate findings (DoE, 2003b)	Alina's Expo report showed that she could draw meaning from a graph on blood glucose concentrations of diabetics and normal subjects: "Normal subjects show a lower blood glucose levels in all instances, i.e. fasting, post meal and with exercise than diabetes Type II and Type I respectively". She also attempted to explain her results in terms of, for instance, exercise. Firstly, she stated that low concentrations are due to the fact that glucose in circulation is used up during exercise. Then, she argued that the effects of exercise in diabetics are great, even though she did clearly provide a reason in her discussion. The interview showed that she was aware of possible extraneous variables that could negatively influence her results, such as bacteria invasion. Hence, she wore gloves prior to testing the subjects' blood.	Alina was able to meet the AS for Grade 11.

Table 4.1b

Alina's developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 2: Construction and Application of Life Sciences Knowledge (for Grade 11)

Assessment Standard (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Accessing knowledge	Use of "various methods and sources to access information" (DoE, 2003b, p. 25)	The interview showed that Alina was able to gather information relevant to her scientific investigation. She reported that "[she] used the internet and encyclopaedia [to search for the information]". Her cousin's information (and that from the library) was also part of "a lot of information" she accumulated. The interview also showed that the information was "the background about glucose levels and diabetes".	Alina was able to meet the AS for Grade 11.

Table 4.1b continued

Assessment Standard (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Interpreting and making meaning of knowledge in Life Sciences	Identification, description, explanation of "concepts, principles, laws, theories and models by illustrating relationships" (DoE, 2003b, p. 25)	Evidently, Alina investigated a medical condition – diabetes. It was her area of interest in which she "explored that quite a lot of people suffer from diabetes". Alina's introduction in her Expo report showed her ability to provide descriptions and explanations of the concepts of "maintenance of Glucose concentration" or glucose homeostasis, and the development of diabetes. As the results of her descriptions and explanations, she could also provide some key scientific/health concepts, which were related to the health condition (e.g., diabetes), such as insulin production and treatment. For example, her Expo report showed that the new knowledge acquired included diabetes being the result of insulin's abnormal production, with Type I requiring patients to use injections of insulin regularly and Type II depending on lifestyle or medication to bring the abnormality into equilibrium.	Alina was able to meet the AS for Grade 11.
	Evaluation of "concepts, principles, laws, theories and models" (DoE, 2003b, p. 25)	The above information indicates that Alina was able to construct science understanding in relation to diabetes. She was aware that "diet, exercise, fasting metabolic rate and certain diseases are among factors influencing blood glucose levels". Indeed, she felt that "[the project helped her to] understand diabetes and…to see the ways that people can deplete the [blood] glucose levels by using natural way of exercising". As stated elsewhere, her questionnaire showed that she thought her original design could be improved. For instance by revising her hypothesis so as to look at "other ways instead of the natural way of depleting blood glucose levels". Moreover, by asking questions like: "Will exercise deplete the blood glucose levels quite a lot or is it just a little bit or is there another way of depleting blood glucose levels except for exercise?"	

Table 4.1b continued

Assessment Standard (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
3. Showing an understanding of the application of Life Sciences Knowledge in everyday life.	Analysis and evaluation of "the costs and benefits of applied Life Sciences knowledge" (DoE, 2003b, p. 27)	Alina also presented some applications that might prove useful in solving problems related to diabetes. For example, she pointed out that exercise is effective in reducing blood sugar level. She then wrote in the Expo report: "Therefore, exercise can be used as a natural way of reducing blood glucose levels in diabetic patients" especially now that diabetes is a major illness in the world. The report showed that she thought, with this natural way (e.g., regular exercise), people may reduce their dependence on insulin and "may be able to obtain better function of the muscles and organs [as well]".	Alina was able to meet the AS for Grade 11.

Elizabeth

Analysis of Elizabeth's written questionnaire showed a number of factors that contributed to her belief that she could do the project. Elizabeth asserted that her interest in the topic on blood pressure and video games enabled her to "stay committed to it [the project]". Furthermore, she stated that she had "the equipment [i.e., Play Station] needed [for tests]". The analysis showed that despite challenges related to access to a blood glucose monitor, she thought it was possible to conduct the tests on different people she was familiar with. Also, with suitable equipment available, "it was possible to analyse the results quite easily".

However, analysis of the interview showed that Elizabeth's study actually proved to be challenging in regard to getting people to come to where the test could be performed:

> …it was difficult to get people to do [the test]…to get people to come to the place to do the test…I was only allowed to have the blood pressure monitor for a certain amount of time. So, it was quite difficult to have to get the people and the blood pressure monitor at the same time and let them come to my house and everything…

The challenges – getting people to come for the test – had an impact on her perception of a scientific investigation, as we shall discover. Her Expo report showed that, similar to Alina's case, her investigation included information associated with identified "independent variable(s) to be manipulated independently of other factors which must be controlled, for a 'fair test'" (Watson *et al.*, 1999, p. 103). Consequently, the type of scientific investigation she designed was one of fair testing (in terms of video games and blood pressure and pulse rate of people of different ages). Analysis of the questionnaire revealed that Elizabeth's experiences made her realise that managing people is a demanding task: "I realised that an investigation with humans is even more difficult since they have their own lives and can't help with your investigation at any time". Furthermore, she felt that investigations are demanding in terms of time and effort because they "take a long time and involve hard work". On a positive note, Elizabeth's questionnaire showed that she felt investigations equip one with rich knowledge related to one's subject's area of interest investigated, as well as new skills.

Science process skills

Elizabeth listed the skills she thought she learnt during the scientific investigation: "…time management, organisational skills, organising information & choosing information that is important". She also adopted certain prominent steps related to the scientific method as she managed her Expo project from start to finish. The steps were learnt at St. Peter's Grammar School, and included:

- Research/Background knowledge: "I first did *research & got background knowledge* on blood pressure, & what effects (sic) it" (emphasis added).
- Experiments/Tests: "I then did the *blood pressure, video game test[s]* on a group of people of varied ages" (emphasis added).
- Interpreting results: "I analysed and organised results".
- Conclusion: "[and finally,] *I drew conclusions*" (emphasis added).

According to Watson and James (2004, p. 38), there are different process skills that are "used throughout the scientific method" (e.g., in the abovementioned components of the scientific method). They illustrated that research, for instance, encompasses **communicating science information** and **analysing investigations**. Moreover, **identifying variables**, **measuring**, **experimenting** are some of the skills associated with testing/experimenting. Formulating conclusions, on the other hand, encompasses **communicating science information**, **inferring** and **analysing experiments**. Hence, I thought it necessary to find out whether Elizabeth recognised these process skills. I thus asked her to tell me about the scientific processes that helped her in her project. I expected her to restate at least one of the processes she mentioned earlier (e.g., communicating science information [p. 100]). However, analysis of the interview showed that Elizabeth's views about scientific processes were embedded in the scientific method and a layout of a project or a scientific report, all of which they learnt at school. She answered:

> Well, we've done lots of experiments at school. So, we've got the whole layout of everything…like, first you get…your aim, and then your hypothesis, and then you must write down your method. And…then you record your results. And, then you like get it all together and compare it and analyse it and then you…do the conclusions. So, the whole layout of my project I learnt. I knew already. So, it was really nice because I knew how investigations are supposed to work.

Elizabeth was able to identify biological phenomenon to be investigated. As stated in her biography (p. 101), apart from her apparent love of medical science, the basis for her investigation was the synthesis of home–based experience with video games and research on video games. Analysis of her Expo report showed that her initial observation was that "[a person's heart beats] faster while playing the game [i.e., video game]". Hence, she sought to find out "how this [increased heart beat] affected your blood pressure". She continued:

> There has been research done on this topic [the effect of video games on blood pressure] before but I wanted to expand it. Most research is done on violent video games and I wanted to see if racing video games would have similar effects. There has also been contradiction on previous research and I wanted to formulate my own opinion and see if similar results were found in South Africa.

Below, I present Elizabeth's descriptions of her research–based process skills. Analysis of the interview indicated how she made an attempt to develop the fundamental skills – **observing and comparing**. The analysis showed that she focused her observations more on the changes, which occurred after she had "done the tests and recorded the results". Her observations involved numbers and units of measure. The implication is that her observations also included ability to read the scientific instruments utilised to measure systolic blood pressure (SBP), diastolic blood pressure (DBP), and the pulse rate (PR). Analysis of the interview further showed that during her observations she calculated averages of the changes in SBP, DBP, and PR: "…I took an average of all…the increases, the amount of increase in each thing". The implication is that the development of her observation skill also included the subsequent constituted averages essential in documenting graphs–based patterns so that she could deduce "the increase and decrease of blood pressure and pulse rate". Therefore, quantitative observations formed the core of her investigations.

Elizabeth was able to note that "most people's blood pressure and pulse rate increased [and that] it was a significant increase". Indeed, analysis of the Expo report showed that the average of the test for SBP (i.e., 12mmHg) was "significant"[12], while that of the DBP (i.e., 8 mmHg) and the PR (i.e., 17Bpm) were both "boardering [sic] on significant". In simplified terms, Elizabeth was able to note an increase in the subjects' SBPs. On the other hand, she had proficiency in noting that "after a period of prolonged playing…[DBP and PR] figures could [also] become significant".

Elizabeth also showed proficiency in noting negative changes in blood pressure and pulse rate of her subjects. It should be noted that she was also aware of the root source of the problem, which explains why she decided to calculate averages of the changes in the variables measured (i.e., SBP, DBP, and PR). She noted that "some of the results did decrease…" The implication is that video games caused an increase in blood pressure and pulse rate. However, technical faults had negative impact on the changes in the pressure and pulse rate. Indeed, analysis of her Expo report showed that experimental errors and/or technical faults (i.e., incorrect cuff size, incorrect positioning of the arm and/or of the body, etc. [her examples]) contributed to the decrease. She expanded on the basis of the technical faults – incorrect cuff size: "I couldn't get different cuff sizes because…you can't acquire [it]. Doctors only have it. So, this home monitor only had one cuff size".

Observing and comparing may also involve "noting similarities and differences" about phenomena investigated (DoE, 2002, p. 13). Elizabeth "didn't really…compare people". Regardless of her assertion that she "didn't wanna compare the things yet", she answered during the interview:

> …but I did notice that people…the only thing if there was any differences like some old people their blood pressure only went up by five, some old people their blood pressure went up by ten. And then some young people [their blood pressure] only went up by…two; some went up by 20 or something.

All these activities (i.e., quantitative observations and comparing) were fundamental to understanding blood pressure in relation to video games.

Quantitative observations (p. 128) also involve development of **measuring** skills using tool(s) for collecting unambiguous observations. Elizabeth's Expo report showed that she was aware that "when measuring blood pressure you will usually receive three amounts" namely SBP, DBP and PR. Analysis of the method section of

[12] Significant changes in Systolic and Diastolic Blood Pressures, and Pulse Rate (provided by Elizabeth):-
SBP: 10-15mmHg; **DBP**: 8mmHg; **PR**: 17Bpm.

her report indicated that she did "*measure* and record systolic & diastolic blood pressure and pulse rate before playing the video game [and] right after the game" (emphasis added). Analysis of her Expo report showed that quantities of the subjects' blood pressures and pulse rates were measured in millimetres of mercury (mmHg) and beats per minute (Bpm) respectively, "for about 15 minutes [for] each [subject (i.e., a volunteer within an age range of 8 to 70)]". She had proficiency in choosing and using appropriate instrument in pressure monitor for her measurements. Indeed, analyses of the interview and the Expo report showed that she "got a lot of information about…how to actually use the blood pressure machine [the monitor]". The report showed that the information included going "through [the associated] instruction manual".

Evidence showed that Elizabeth did measure variables. However, she had misconceptions in relation to the concepts of *accuracy* and *precision* in measurements and *controlling variables*:

> Well…[I had] control treatment [protocol], like I told the people: don't drink too much caffeine before 'cause that could increase blood pressure. And don't overexert yourself. And…I'd quite a few restrictions, but not too many 'cause if you play video games you're not gonna have those restrictions in everyday life. So, I also wanted to see, it must be true to everyday life, [but it can't] be like perfect example.

Elizabeth's Expo report indicated that her methods and procedures involved carrying out tests, measurements and **recording** the results. Similar to the preceding cases, the descriptions of her ability to **communicate science information** and record information are presented concurrently.

Elizabeth like other Expo students, selected suitable means to communicate with relevant people. Her exhibition involved a poster, which represented "sort of like just a whole summary [of her project]". She provided an illustration:

> Well, its just helps when you're looking at the poster…You can see what actually went on, like the blood pressure monitor; you can see what I actually used then. Those… that's the equipment I used then; [and]…how people were playing.

Analysis of the interview also showed that Elizabeth was able to present her work in written forms, as evident in her Expo report. The interview and the report also revealed that she was able to utilise the conventional mathematical and pictorial forms of representing her science information, which included colourful bar charts, tables, photographs/pictures, diagrams, and cartoons. The interview showed that these forms, especially the graphs, were used to enable people to visualise and understand the results of the tests conducted: "So, while using the graph you can actually see what happened in the test, because it's like an image…it's easy to understand, yes".

According to DoE (2002), "communicating…involves more conventional science *forms* such as tables…[and] graphs" (p. 14; emphasis added). Evidently, Elizabeth was able to select these suitable forms to represent her information. However, she did not understand what *forms* of communicating science information meant:

Interviewer (I): OK. Tell me about the simple and easier forms of communicating [science] information that you used. Forms of communicating information that you used. What were the ones that were simple and easier to use?
Elizabeth: So, like presenting my information to other people?
I: Yes.
Elizabeth: …I think it was quite simple to…find…just convey my message to people, but then…yah.
I: You can also tell me about the sophisticated and challenging forms [of communicating you science information].
Elizabeth: OK. It is quite challenging. So, now I was talking to a judge and then I told him everything. And, then…once they ask you a question that you hadn't really researched it wasn't challenging, but you had to think quickly…you had to tell them…you don't wanna lie to them either…So, if they ask you question that you didn't really do, you want to answer it as well as possible. But if you hadn't done a thing, you just have to tell that to them.

Her recorded results were the measured systolic and diastolic blood pressures and pulse rate quantities. Analysis of the report showed that she had a "record sheet and pen". The analysis showed that the "sheet" was her journal in which – based on evidence from the analysed interview – she recorded "what was happening". She elaborated during the interview: "So, I just measured their blood pressure, *record* what it was, see what they did in a video game, and then *record* the…blood pressure again" (emphases added). So (2003) showed that students' common ways of recording and representing data are the same. On that note, Elizabeth's colourful bar graphs/charts were not only used in data representation but also to record information from her analysed interviews. These charts were coupled with tables in which she recorded, for instance, test results of "the effect of video games on blood pressure" using the game Sled Storm; "average increases from the test"; and "summary of the test results".

Similar to communicating science information, there are "suitable form[s] in which to record the information" (DoE, 2003, p. 13) associated with one's investigation.

Tables (DoE, 2002; So, 2003) and graphs (So, 2003) have been given as examples of these forms of recording information and data. Moreover, it has been shown that students may be better at working with tables than graphs (p. 130). Elizabeth was thus asked to group the forms of recording information inherent to her project into those that were simple and those that were challenging. Again, Elizabeth did not understand what *forms* of recording information meant:

Interviewer (I): OK…which forms of recording that information were easier to do?
Elizabeth: Recording information?...I only really had one thing, that's the thing, 'cause I only recorded the results of the test. So, I didn't really have more than one thing. But I think finding the information was the easiest part 'cause there's so much on blood pressure, you know, so…
I: So, which form of recording the information was challenging?
Elizabeth: …like I said, OK, recording information I think it was just quite difficult to get all the results from people because sometimes the machine wouldn't work properly, you know, to give say error or a pulse result. It was quite difficult to record the blood pressure. But, as I said, there's not many things I did to have to record, so I can't really look at the difference.

Analyses of Elizabeth's Expo report, the questionnaire, and the interview also revealed findings about Elizabeth's development of her **sorting and classifying** skill(s). Her Expo project showed that she did not group the subjects on "races, ages, genders, [etc.]" basis – which explained why she did not perform any form of comparison. However, during her reflection on interpreting information, she responded that she grouped her data into "increase" and "decrease" so that she might analyse it: "…OK…I *analysed it* like I told you just now with…*increase* and *decrease*. And, then after that I made *tables*…just to…*sort it properly*" (emphases added). Yet, she was not able to describe how she sorted and classified items/objects when asked to reflect on sorting and classifying items/objects she utilised. Her questionnaire revealed that she thought sorting and classifying were only applicable to certain kind of objects: "[I] didn't really have to group [them (i.e., "TV and the video games"] or anything *because they [were] all like everyday objects*" (emphasis added).

Elizabeth was also challenged to develop her proficiency in **interpreting information**. The details of her performance on this skill were based on So's (2003) analytical framework, which encompassed, for instance, gathering and making sense of data. DoE's (2003) framework in relation to the descriptions of students' proficiency in gathering information from relevant sources (p. 132) was included.

Analysis of the interview showed that Elizabeth had Internet at home as well as Encyclopaedia. These resources were used to gather background information on blood pressure. The reported source of Elizabeth's (and of other cases in this study) background information (i.e., Internet) authenticated Valauskas and Ertel's (1996) opinion that the Internet has transformed the science education landscape. It was also essential that Elizabeth was able to acknowledge sources of help from other people who assisted her with some level of expertise and/or resources essential to make her study a success (So, 2003). She acknowledged "doctor MacDonald (footnote 4, p. 92) for help with analysing results and understanding concepts". Analysis of her Expo report showed that the acknowledgements also included one particular lady who provided her with the book which was "basically all about conditions…that include blood pressure and all that kind of stuff".

Gathering and making sense of data involves proficiency in using equipment (So, 2003). Elizabeth's Expo report showed that she had electronic equipment and the associated material in blood pressure monitor, television and play station and sled storm video game to collect data on blood pressure. The material utilised when needed included record sheet and a pen. Her report showed that all these were, according to her, "apparatus" she used "to do a test, and measure [and/or gather systematic data on] blood pressure before and after individuals have played a video game". In So's (2003) study, primary students were able to "make sense of their data by using scientific equipment and empirical observation, and to translate these observations into usable data for interpretation, as well as gathering data in an organized and logical manner" (pp. 187-188). The "apparatus", such as the monitor enabled Elizabeth make sense of her data. Analysis of her report showed that this sophisticated electronic equipment was instrumental in the production of data that could be interpreted. For instance, her quantified blood pressures recorded were the result of the monitor's readings according to the changes in blood pressure of each subject and the subsequent empirical observations made.

Representing data is also essential in interpreting information (So, 2003). This was instrumental in, for instance, the discussions of Elizabeth's data. Elizabeth utilised graphs and tables, as well as photographs to record and represent her data (pp. 147-148). Analysis of her Expo report showed that she used photos as pictorial forms of representing relevant visual information from her "literature study" to illustrate: (a) the advanced "device used for measuring blood pressure"; and (b) sections of the brain that were stimulated when children were subjected to violent video clips. The analysis further showed that these pictorial information, and diagrams and cartoons, were used to supplement information in written text, which provided details on the blood pressure, pulse rate, video games, and nervous and circulatory systems. Furthermore, Elizabeth used the tables and the graphs to provide clear, compact and concise information about the different quantities and trends in relation to blood pressure and pulse rate of her subjects.

Elizabeth's interpretation of information had to include analysing data to reach conclusions (So, 2003). She reported during the interview:

> Well…I analysed it like I told you just now with…increase and decrease. And, then after that I made tables…just to…sort it properly. And, then I made that graph [on the poster] to…'cause it's easier when it's got…when you got…what actually happened. And, then I've also got the tables that I can compare over there.

It should be noted once again that she designed fair tests that were associated with video games and blood pressure and pulse rate of people of different ages (p. 144). Her results enabled her make logical conclusions and suggestions. For example, in her Expo report she was able to conclude that playing video games increased both blood pressure and pulse rate of people who were tested. She also concluded that a considerable increase was more pronounced on systolic blood pressure than diastolic blood pressure and pulse rate because the latter (i.e., the pulse and diastolic pressure) were bordering on standard significant values (i.e., 17 Bpm/20-30 Bpm and 8 mmHg/10 mmHg). In the light of the conclusions, she suggested that people should spend "moderate" time playing video games because "this will give their bodies time to restore [the equilibrium of blood pressure] and won't put continuous strain on their bodies". She went on further to say that "people that already have conditions like Pre–hypertension or bordering on high blood pressure should be cautious with the amount of time they spent with these games".

As stated previously (p. 134), present trends or previously known information (drawn through interpreting information) form the basis for students' estimations or forecasts of future observations (**predicting**). When asked about predictions she made, Elizabeth's questionnaire showed that she was able to make estimations about blood pressure. Firstly, she disclosed the basis of her estimations: "It felt like my heart beated [sic] faster when playing video games". Analysis of the questionnaire showed that this experience enabled her to predict that "video games would increase blood pressure". Lastly, evidence from the written questionnaire showed that her proficiency in predicting was also rooted in research on blood pressure and pulse rate:

"This [prediction] was also based on what I had known about blood pressure [and pulse rate]".

In this study, students' proficiency in making a *testable assumption* of a relationship between factors, and the subsequent explanation for that relationship was essential (DoE, 2002). Evidence from Elizabeth's Expo report indicated that she was also able to make presumptions, which led to the investigation (i.e., **hypothesising**). She presumed that "playing video games will increase blood pressure and pulse rate values of people of varied ages". She substantiated her presumptions in the questionnaire: "I presumed that video games did have an effect on blood pressure & pulse rate. My hypothesis was that video games increased blood pressure & pulse rate". Though she did not specifically state reasons behind her assertion, analysis of the questionnaire showed that the basis of her predictions – experiences with video games – were pivotal in her assumptions.

It should be noted that a research problem, which is normally framed as a question set a precedent to a hypothesis (p. 135). As referred to elsewhere (p. 144), Elizabeth started her project with research or background knowledge of the phenomenon investigated. It was, therefore, imperative that I found out whether she had some questions in mind prior to the investigation. Analyses of the interview and her Expo report showed that she had proficiency in **raising questions** about video games and blood pressure. Evidence from the interview showed that she raised two main questions. She revealed: "…basically…the question that I asked was…I wanted to know the effect video games were on blood pressure [to test the hypothesis]". She added: "…the other question also I asked was…how significant the effect was."

Raising questions also involves "rewording the question to make it scientifically testable" (DoE, 2002, p. 14). Analysis of the interview showed that testing played a major role in ensuring that her questions can be tested through experimentation. She answered:

> Well…that's why I got the test because *the test* could answer those questions for me. 'cause the results from *the test* could tell me if video games did increase blood pressure or not. And, they could also tell me how significant the effect was. So, through my whole test, that's my scientific…method test…that's how I concluded….the question. That's how I answered the question (emphases supplied).

It should be noted that it was not clear as to whether "the test" she mentioned referred to a pilot test or a test during implementation stage because analysis of the Expo report showed that she initially "did test on 3 boys & middle age female". If she was referring to the pilot study, then the implication is that she conducted the pilot test to ensure that the first question, in particular, was scientifically testable.

Elizabeth was expected to show proficiency in **planning scientific investigation** as well. According to DoE (2002), a point of departure in planning science investigations is working on a research question to make it into a testable prediction. Elizabeth's Expo report (e.g., journal section) showed that she started her investigation with Internet–based research as she "looked around and thought what problems…there're on" and what interested her. The research was confirmed in the questionnaire: "I first started with research". She started with a research on blood pressure and "what effects it" (p. 144). She added:

> And, I went into the Internet and I looked at all different kinds of…Expos that had taken place. And, then…yah that's how…in the end…all the things [were] put together like my brother playing the video games, and that's a problem 'cause he said he's irritated afterwards, and because I was interested in it, and because I found the topic. It all sort of came together. And, then I decided to do it.

Analysis of her Expo report (i.e., journal section) also provided an insight on other elements of planning scientific investigation Elizabeth addressed prior she "finished planning" the investigation. Elizabeth:

- Raised a question about a situation and formulated a hypothesis: "[I] made focus research question & hypothesis".
- Devised methods of collecting data and how to collect relevant data and/or information: "[I] made a list of apparatus needed and how I was going to find my information".

According to DoE (2002), Elizabeth should be able to identify, for instance, methods, and evaluate a plan for a fair test. She wanted to investigate blood pressure and heart rate to understand the concepts and functions of blood pressure while ensuring that her research design was appropriate. Evidence in her Expo report showed that her plan encompassed "variables for the test"; "control treatment"; and subsections that covered issues, such as "Is the test sample large enough", "Is method reliable" and "Is this investigation reliable". She also had a subsection "Graphs to display results".

In summary, at the beginning of her plan, Elizabeth started with gathering relevant information (i.e., *research/background knowledge*). Then, she formulated a focus research question and the associated hypothesis (i.e., *problem/research question and hypothesis*). Her plan also included:

- *Variables* to be tested: For instance, "Dependent variable: the blood pressure of each person" (emphasis in the original). She also had "equipment needed for test" associated with the variable in, for example, video game and blood pressure monitor.
- *Evaluation of her plan*: It should be noted that she intended to "gather all information: analyse and evaluate information and draw conclusions". Consequently, in order to control the interfering variables, such as caffeine or high energy drinks (her examples), she had what she called a "control treatment" in place to ensure that her findings were "as truthful as possible to normal everyday living". Furthermore, she was able to evaluate her method. She wrote in the Expo report: "Yes [the method is] reasonable [sic] reliable".
- *Ways of representing data*: For example, "a bar graph will be used showing the increase and decrease of blood pressure and pulse rate".

I also asked Elizabeth to tell me more about the practical part of her investigation – **conducting the investigations**. Her account should have encompassed how she "[manipulated variables] while controlling interfering variables, measuring the variables, recording data, interpreting data to make findings, and reporting in qualitative and quantitative terms" (DoE, 2002, p. 14). She thought that this process skill entails "basically setting up all the equipment; and getting the results; and recording them; and making sure that they were as correct as possible…" Analyses of the questionnaire revealed that also included were the analyses and the organisation of the subsequent results.

Analysis of her Expo report showed that she set up a situation in which the change in the dependent variable can be observed while she controlled the interfering variables. The report clearly showed that the following were "the variables for the test" that were observed:-

1) The participants (considered as independent variable).
2) Each participant's blood pressure (considered as dependent variable):
   a) Before and after the testing their blood.
   b) "Compared to others".
3) Equipment (i.e., the monitor) and video game used and "the environment in which the video game is placed" constituted fixed variable.

Life Sciences knowledge

Elizabeth's investigation on the effects of video games on blood pressure formed the basis for descriptions of the new knowledge she had developed. Similar to the previous case, the analyses showed that the process of the Expo investigation and the scientific skills she developed formed the basis for the development of her scientific understandings. Tables 4.2a and 4.2b below present summarised descriptions of the knowledge elicited from the analyses of Elizabeth's three sets of data.

Table 4.2a

Elizabeth's developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 1: Scientific Inquiry and Problem–solving Skills (for Grade 10)

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Identifying and questioning phenomena and planning an investigation	Generating and questioning "hypotheses based on identified phenomena for situations involving more than one variable" (DoE, 2003b, p. 17) – for Grade 12	Elizabeth's Expo report showed that she was able to note that video games had a particular effect on people. For instance, she observed that the video games do not only change peoples' moods but they also cause a heart to beat faster. She also discovered research inclination towards *violent* video games and a contradiction in previous research on video games. Her interview and her completed questionnaire showed that she could hypothesise that the effect (e.g., increased heart beat) of video games on people of varied ages could be linked to changes in their respective blood pressures and pulse rates. It should also be noted that she was aware that, for instance, blood pressure in turn is affected by adrenaline response: "…it's not likely that people's blood pressure will decrease because…you get that adrenaline response and then your blood pressure goes up…"	Elizabeth was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.
	Designing "tests and/or surveys to investigate these variables" (DoE, 2003b, p. 17) – for Grade 12	Elizabeth's scientific investigation was categorised as fair testing. She had proficiency in addressing the issue of "fair" tests. Her Expo report showed that she had proficiency in designing simple experiments to find the correlation between racing video games and the two factors related to heart beat namely blood pressure and pulse rate, through pilot tests with "3 boys & middle age female" prior to conducting the main tests.	

Table 4.2a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Identifying and questioning phenomena and planning an investigation	Evaluating "the experimental design" (DoE, 2003b, p. 17) – for Grade 12	Elizabeth stated that she was content with the outcome of her project: "OK…I answered my question in the end..." However, she looked at factors, such as gender, race, duration of the tests, and sample size in her quest to evaluate her experimental design. She thought she would have "[compared] genders and see if…males have a higher blood pressure when they play video games with females". Also, she would have investigated different ethnic groups to check "if there's a difference"; test "the effects of prolonged playing"; and test a bigger sample of "older and younger people".	Elizabeth was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.

Table 4.2a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Conducting an investigation by collecting and manipulating data	Systematically and accurately collect data using selected instruments and/or techniques (DoE, 2003b) – for Grade 11	Elizabeth's Expo report showed that blood pressure monitor was one of the "equipment needed for her test". She knew how to use the monitor properly to collect data related, for instance, to blood pressure because she "got a lot of information about…how to actually use the blood pressure machine [the monitor]". Her Expo report also showed that she had a setup in which the participants' blood pressures were tested using the equipment before and after each participant played a video game. Her interview also showed that prior to the recording process of the data on blood pressures of each participant, she "looked at the numbers and…took an average of all the peo[ple]…all the increases, the amount of increase in each thing". Her Expo report showed that she was then able to systematically record the subsequent data on systolic and diastolic blood pressures (SBP and DBP), and pulse rate (PR) in tables. It should also be noted that she listed "variables for the test" in the report [e.g., *participants* (considered as independent variable) and *their blood pressures* (dependent variable)]. On that note, she had considered how "fair" her experiments were. For instance, she checked the possible influence of "caffeine or high energy drinks", strenuous activities and the components of equipment she used (i.e., cuff sizes) on blood pressure of the participants. Elizabeth identified limitations of her instruments and techniques, and measures to be taken to alleviate the limitations. Firstly, she had only "one cuff size" when measuring her subjects' blood pressures. Because she realised that the limitation might have had an impact on her readings, she calculated the abovementioned averages. She also consulted an expertise to explain unexpected changes (i.e., the decrease) in blood pressure in some cases. Secondly, she realised that caffeine and/or overexerting themselves might "increase blood pressure". This limitation influenced her to set up a few restrictions to her subjects, such as avoiding too much caffeine and "overexerting" themselves, bearing in mind that she had to keep conditions as natural as possible.	Elizabeth was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.

Table 4.2a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Conducting an investigation by collecting and manipulating data	Selection of "a type of display that communicates the data effectively" (DoE, 2003b, p. 21) – for Grade 11	Elizabeth had a poster to summarise and display all the results and plans to communicate her science information in mathematical and pictorial forms as part of the Expo exhibition. The exhibition also encompassed her report to provide a more detailed account of her project for the specific audience.	Elizabeth was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.
3. Analysing, synthesising, evaluating data and communicating findings.	Analysing, synthesising, evaluating data and communicating findings (DoE, 2003b)	As stated previously (i.e., in 2.), Elizabeth was able to systematically record the subsequent data on SBP, DBP and PR in tables. The tables had a corresponding bar chart. These also constituted forms of data representation, which enabled her to interpret her data, and present summarised results and conclusions on her poster. Indeed, she stated during the interview: "I just noticed [from the trends on the graph] that video games did increase blood pressure and pulse rate". She also had proficiency in explaining that the increase was due to the changes in SBP, DBP and PR. After all she claimed that she "found out a lot about blood pressure because of the information from the Internet and…know like quite a few things about blood pressure". Elizabeth's examination of the graph enabled her to conclude that "video games do increase blood pressure and pulse rate of individuals of varied ages". Furthermore, she concluded that while the effect of the video games was "bordering on significant" for both DBP and PR, it was significant for SBP.	Elizabeth was able to meet the AS for Grade 10.

Table 4.2b

Elizabeth's developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 2: Construction and Application of Life Sciences Knowledge (for Grade 10)

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Accessing knowledge	Use of "various methods and sources to access information" (DoE, 2003b, p. 25) – Grade 11	Elizabeth's Expo report and interview showed that she was able to access relevant information on blood pressure. For instance, she was able to supplement information from doctor MacDonald and one particular lady who provided her with the book which was "basically all about conditions…that include blood pressure and all that kind of stuff" with background information from Internet at home, as well as Encyclopaedia.	Elizabeth was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.
2. Interpreting and making meaning of knowledge in Life Sciences	Identification of "concepts, principles, laws, theories and models" in the context of everyday life (DoE, 2003b, p. 24)	Elizabeth's Expo report showed that she conducted a research on a biological phenomenon – blood pressure. It was her area of interest in which she explored in terms of SBP, DBP, and PR. Hence, the key scientific/biological concepts that Elizabeth developed included blood pressure. For example, her Expo report showed that she believed that "*when measuring blood pressure you will usually receive three amounts* [namely SBP, DBP and PR]" (emphasis in the original). She was able to use pictorial forms to identify structures (e.g., blood vessels; brain's amygdala [her examples]) and biological processes (e.g., changes in blood pressure; signal transduction) associated with systems that are affected by video games (e.g., circulatory and nervous systems).	Elizabeth was able to meet the AS for Grade 10.

Table 4.2b continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Interpreting and making meaning of knowledge in Life Sciences	Description and explanation of "concepts, principles, laws, theories and models" (DoE, 2003b, p. 24)	Part of the new knowledge acquired included blood pressure being the result of changes in SBP, DBP and PR when people play video games. Elizabeth could briefly explain the cause of the positive change in blood pressure – adrenaline response: "…it's not likely that people's blood pressure will decrease because…you get that adrenaline response and then your blood pressure goes up…" She was aware of the causes of the problems of blood pressure, such as hypertension: "People that already have conditions like Pre–hypertension or bordering on high blood pressure should be cautious with the amount of time they spend with these games". She used her "literature study" section in her Expo to list factors that causes blood pressure problems, such as stress, nutrition, and drugs. Most importantly, she could also describe and explain blood pressure in terms of hypertension. For instance, she stated that it is "diagnosed if secondary signs of high blood pressure are present, along with a prolonged high systolic pressure reading over several visits". According to her, a research study has shown that people with no known history of hypertension normally have 112.4 mmHg and 64.0mm Hg as averages for SBP and DBP respectively.	Elizabeth was able to meet the AS for Grade 10.
3. Showing an understanding of the application of Life Sciences Knowledge in everyday life.	Analysis and evaluation of "the costs and benefits of applied Life Sciences knowledge" (DoE, 2003b, p. 27) – Grade 11	Elizabeth's Expo report presented a new knowledge she developed in relation to the impact of video games on the health and lifestyle of people who love these games. She suggested that "people should not stop playing video games completely. They should rather moderate the amount of time they spend playing video games". She pointed out that this is crucial, particularly for people who have "Pre–hypertension".	Elizabeth was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.

Gertrude

Before I present the descriptions of Gertrude's scientific skills and science knowledge, it should be noted that her Expo project was not a complete version because she pointed out that it was an invention and had to be patented. She elaborated out during the interview:

> …there were stuff that I left out just so that nobody else can do my project, but when I'd my judging session I told them about it…so still my project has to able to be patented. And I then I'm patenting my project through *Sanco* (footnote 4, p. 92), which is a government organisation in the Trade and Industry sector. And, I've it provisionally patented for next 12 months.

When asked about what made her think she could do the project, Gertrude reported in her written questionnaire several attributes she felt contributed to her competence. The attributes included:

1. *Awareness of her abilities*: "Myself, I know what my abilities are, I know what I am capable of doing".
2. *Her awareness of expectations*: "I know what is expected of me, what I need to achieve".
3. *Her personality*:
   (a) She thought she was a perfectionist. She elaborated: "everything has to be done perfectly with no errors to questions".
   (b) She thought she was a determined person as well. She reasoned: "nothing will stand in my way. I can get over every pothole. I can achieve whatever I want to because I believe in myself, it is my personality".

Despite her beliefs, Gertrude encountered some challenges she had to overcome when doing her Expo project. Analysis of the interview showed that the challenges were embedded in, *inter alia*, the design of her investigation and the background research. Evidence showed that she had to overcome skepticism about the project itself, and a lack of trustworthiness of the subsequent data from her experiments and information she had to gather from the Web. She explained:

> …at first there was…a little bit of hesitation into whether this could be a good project. What if I get people the same…It was challenging and how I was gonna overcome those, and…keeping my variables constant so that every person was the same and there was no exception for some people not being the same…stuff like that, like the research. I mean the Internet constantly contradicts itself. I honestly think the Internet is one of the worst places to research something…I would say it's [Dogpile] probably one of the best research engines to use. [But] Google constantly contradicts itself…it gives you borderline information. And, also you get different information from each [web]site, which you've to put together...

I also asked Gertrude to tell me about her thoughts concerning science and/or scientific investigations. It should be noted that she had enough experience with the Expos. She had revealed during the interview: "I mean this is my third science Expo, and I know, I remember each science Expo like I know what I did, I know my process, and it's a long process". Consequently, her responses on science and scientific investigations might haven been embedded in her experiences of Expo projects. As referred to elsewhere (p. 127), scientific investigations may be categorised as making things or developing systems and pattern seeking. Watson *et al*. (1999) stated that the former encompass *technological investigations* in which students design, for example, systems to meet human needs. According to them, the latter involves carrying out *surveys* (e.g., in health sciences [e.g., genetics]) and then *seeking patterns* in findings. Gertrude's biotechnological investigation was a survey, which resulted in an "invention" or a development of a Fundus identification programme in which both a Fundus camera and a mathematical formula were used. Therefore, the investigation was categorised as pattern seeking that involved making things. Analysis of the questionnaire showed that her reflections on investigations were embedded in her understanding of: (a) the nature of science, (b) the process of investigation itself, and (c) the associated scientific attitudes. For example, she thought her project made her:-

1. "[Realise] how science can be applied but changed at the same time". The implication is that she recognised that science, by virtue of being applicable, is not absolute (i.e., independent of other disciplines).
2. Understand that scientific investigations require:
   (a) impeccable execution, which includes "how to do a proper investigation", "how to do accurate research"; and
   (b) consideration of ethical issues such as "how to get consent" and "how to ask in the correct manner".
3. Recognise problem solving attitudes that are in tandem with the investigations, such as "how to be confident…conquer something you believe in…to make dreams reality".

Science process skills

Gertrude also reported in her questionnaire the skills she thought she learnt during her Expo project. Analysis of the questionnaire showed that she learnt at least three science process skills. The analysis showed that firstly, she **designed her investigation**: "I started off by seeing how I would wanted to carry out my investigation". Secondly, she worked on **raising questions**: "I wrote down any questions I needed answers to". Thirdly, she engaged in **analysing** during two feasibility studies (i.e., surveys with a total of 500 randomly selected subjects) and the main study (i.e., with 500 subjects). Evidence from the questionnaire showed that, after she analysed data from 200 people and "realised it was safe to move on", she repeated the experiments with "another 300 people and analysed them [as well]". Fourthly, she "then did a research". Watson and James (2004) illustrated that gathering background knowledge melds with **communicating science information** and **analysing investigations**. Finally, after she "wrote up" her Expo report, she "did a PowerPoint presentation" and "did a poster board", which were then exhibited at the 2007 Expo. These suggested that she **communicated science information**.

Analysis of the interview showed that some of the abovementioned skills were part of the scientific processes Gertrude asserted helped her during her Expo project and were "very similar to what scientists do". She continued during the interview:

> Like they [scientists] research an idea about what they think and they like go through all the options looking at what they could do, what they can improve even at the end of the day. And, it's not a process that takes place quickly. And, you've to keep on going back and you keep on having to verify new things as new equipment's made, as new…mathematical formulas coming to being…you've to be able to adjust to your project. It can't be like fix, finish and done…'cause things change and that's what the world's about…

In the light of the abovementioned excerpt, Gertrude's views regarding the skills she utilised also blended with the attitude common to scientists. That included the scientific attitude that embraces systematic and logical approach not "fix, finish and done"; and flexibility and critical reflection of one's work such as, for example, "you've to be able to adjust to your project".

Gertrude was able to identify biological phenomenon to be investigated. As referred to elsewhere (p. 113), her diabetic grandfather's Fundus photograph was the basis for her investigation. Her Expo report revealed that the photo prompted her "to ask the questions as to whether all Fundi look the same". Consequently, she sought "to determine whether a photograph of the back of the eye can be used to identify a person" using both a rare and sophisticated piece of equipment in the Topcon Fundus camera and a mathematical formula. The formula was instrumental in converting a person's set of fundus measurement into a distinctive Fundus Identification number.

Hence, in this sub–section I present the descriptions of Gertrude's process skills that were applicable to her study and were therefore used by Gertrude. Analysis of the interview presented her own account of how she attempted to develop the fundamental process skill – **observing**. Observation may encompass "ordering and sequencing events” (Devereux, 2000, p. 13). She was able to order and sequence events that made up her observation. She responded:

> Well, I analysed each of my 1000 pictures, recorded my results…got my ID number from…the pictures…and then basically developing a programme that can look at all the numbers, and saying that none of them are corre[ct]…none of them are the same, therefore being able to use it as a method of identifying a person.

Students’ proficiency in observing may also involve description of patterns drawn from their data (Devereux, 2000). Analysis of the interview showed that Gertrude’s observations also involved looking closely at similarities in data based on the subjects’ Fundus photograph prior to describing established patterns: “…every single picture was different even though they looked similar and sometimes they were only like very small differences”. She commented on the apparent similarity in the patterns: “But, that…it really can’t be it in that I needed like a specialised programme developed to do like these measurements automatically not manually, which I did then”.

Gertrude went further to disclose the challenges she was confronted with in relation to the development of her quantitative observations during the interview. The reported challenges also showed that she was able to continuously evaluate her experiments (i.e., measurements were repeated to obtain more reliable data) as she conducted her investigation:

> I would say accuracy…it’s very hard to be accurate when you’ve to take your measurements manually…but…sometimes I’d to like redo the same picture like may be five, six times to make sure that I actually got it correct and that I was happy with it, ‘cause I did every single picture. I knew kind of where to stop and where to start my measurements from…you kind of like you learn it…over time…I mean now if you gave me a picture I could tell you exactly where to start and where to stop. But, obviously it takes time and…yah, that was probably one of the most challenging parts.

Her Expo report showed that the above excerpt was part of the “questionable factors of the investigation”. Analysis of the report showed that this problem of “inaccuracy in taking the measurements [manually]” enabled her to note that an improved method was required. She felt that a “specialised equipment and computer programs to take measurements automatically could be developed”. Nevertheless, she was able to note and conclude that:

1. “All people are different and this goes also for the Fundus” (evidence from her Expo report). The implication is that she noted that a Fundus photograph could be utilised to identify a person because people have their own unique genetic make–up that is reflected in their respective Fundi.

2. Fundus–based identification is reliable, instantaneous and could have wide range of everyday applications compared to other methods (i.e., fingerprints):
   a) "The internal characteristics of the eye cannot be changed deliberately" (evidence from her Expo report).
   b) "In short period of time the person can be identified using this method [i.e., in less than 10 minutes]" (evidence from her Expo report).
   c) "My method's…very good 'cause it can be used in small children, which not the other methods can be" (evidence from the interview).

This issue of the improvement of the reliability of Gertrude's measurement using specialised equipment and computer programs clearly indicated that her quantitative observations involved development of **measuring** skills. Analysis of the interview showed that she was able to measure variables (i.e., stable distances through various internal parts of an eye). The variables were essential for her to calculate the numerical properties of her subjects' Fundus photos using the sophisticated equipment and two sets of mathematical formula. She elaborated:

> …I took three, four different measurements, but one can be joined to make just one measurement, so about three different variables that were stable over time, they never change over time…and I took those measurements of every single photograph of the same magnification and then I substituted them into a formula, mathematical formula. That was a ratio relationship, so that it wouldn't…so, [that it] wouldn't make difference to the pictures magnified, so, I'm looking at the relationship between the three numbers. And, I got…100% success.

Furthermore, we conversed about the issue of accuracy and precision in measurements. Analysis of the interview showed that Gertrude was aware of the need to repeat and check her measurements and select suitable measuring techniques to establish trustworthiness in her data. It should be noted that Gertrude recognised that "the formulas [used] are ratios and measurements in terms of millimetres are not necessary for this method". She elaborated on the utilisation of the formula:

> I'm not saying that every single one of my measurements are accurate. That's the reason why I've got two formulas. The first formula's got variable, and what it does, it's like basically a plus formula, and it doesn't compound minor inaccuracies. So, if I did make one out maybe, it'll only show up and say the…like six decimal places, something like that. So, [it's] hardly anything, whereas my other formula if I made a mistake it'll show up and say the third or fourth decimal place.

As referred to elsewhere (p. 130), So (2003) description of representing data encompassed recording of information and data. Likewise, the descriptions of Gertrude's development of skills in **recording information** and **communicating science information** are presented together.

Gertrude's numerical measurements made from left and right eyes had to be recorded. She was able to develop her proficiency in recording information associated with the measurements. Her Expo report showed that she selected a suitable table format to record and represent science information. Analysis of the interview showed that she had a file in which she recorded raw data. Gertrude felt that recording the information was not challenging at all: "That wasn't challenging…keeping track of it, keep them in a file when you're done with your work". Her descriptions showed that computing devices were used to produce functional (i.e., numerical) data that were recorded in the tabular form and ready for interpretation:

> Well, I've…like a rough work book, and like a file and stuff where I keep all my like information and like when I did my measurements I hand–write them and then type them up into Excel and…like any other processes like working up formulas…You just use the file and you print out sheets from the computer like tables, writing the…all the measurements under each heading and then you just file it and then when you're done all of them you type them up.

One of the science process skills Gertrude asserted she had developed was communicating science information (p. 163). Analysis of the interview showed that she selected suitable means to communicate her results with the fellow Expo participants, the public, and the judges. It should be noted that "[she] typed everything upon [Microsoft] Word [to produce prose text]" as part of her exhibition. Gertrude's exhibition (Figure 4.1) involved a poster, Expo reports, an eye model, and a laptop. She thought presenting information on the Expo report and the poster had to be different in terms of the quantity of information. She explained: "Like…in your book [Expo report] you need to elaborate more on information, more than your poster board [when presenting science information in pictorial and mathematical forms, and written forms]". She elaborated on the written form of representing information and data on a poster:

> So…everything has to be on point form. It makes it easier for you to read and it makes it easier for people to understand your project…I mean you just…need to have it like organised. It needs to go like scientific process like you can't start with method and end with introduction.

Her interview also showed that she had proficiency in utilising a more sophisticated form of presenting her science information – a PowerPoint presentation. Evidence from the interview showed that the PowerPoint format proved useful in summarising the information: "I summarised everything into a PowerPoint presentation".

Furthermore, she used the presentation for people who wanted narrated explanations in addition to the prose text: "And, also what I did is I made a presentation, like a PowerPoint presentation…for people who didn't only want to read".

Figure 4.1. Exemplar of ESKOM Expo exhibition – Gertrude's celebrated Expo project. From "Photo Gallery" by *Cape Town Expo for Young Scientists* (n.d.*d*)

The interview revealed one conventional mathematical form of representing information, which was coupled with the extensively used prose text: "I made a lot of information, writing information, table writing". Other typical forms of representing science information were graphs (Figure 4.1). However, she asserted that she did not use them. She elaborated: "I mean my project's got no graphs on it. There's nothing I can do a graph on". Additional forms (i.e., pictorial forms) she utilised (on the poster) included colourful photos of the internal parts of human eyes. Nevertheless, the photos, together with the eye model, were not mentioned during the interview.

As stated elsewhere (p. 130), students may be better at working with tables than graphs. In order to deduce whether she worked better with tables than graphs (she did not mention them), I inquired about the forms of data representation in terms of those that were easier to do and those that were challenging. Her responses were only focused on organisation of her information on the poster and the report.

In order to organise her recorded results (e.g., in the table), Gertrude had to create categories for **sorting and classifying** collected data as well. Analyses of the interview and the questionnaire showed that she was not able to report how she sorted and classified her data. Evidence showed that she thought the equipment and instruments used were the only items that qualified for classification. She answered during the interview: “I borrowed a camera for…to use for my project…from [a] very nice man who let me borrow it”. She added in the questionnaire: “It’s the only thing that can take the pictures [that could be classified]”. Nevertheless, analysis of her Expo report showed that she developed her classification skills through grouping her data in order to present the subjects’ 10–digit Fundus ID numbers of their eyes. It should be noted that she labelled the first mathematical formula “Variable” and the second one “Accurate”. Hence, she selected a suitable system in a table format and named them “VARIABLE” and “ACCURATE” prior to recording the data related to Fundus ID numbers.

With the data related to Fundus ID numbers now organised in a table, Gertrude sought to make sense of her data and information (**interpret the information**). The same analytical framework used in the previous cases was adopted (i.e., gathering and making sense of data, data representation, analysing data and drawing conclusions), as well as the DoE’s (2003) framework in relation to the descriptions of students’ proficiency in gathering information from relevant sources.

Evidence from the interview showed that to search for biometric information related to her study, she predominantly utilised the Internet: “I used the Internet to research other methods of biometric identification as well…like present methods and emerging methods, so a lot of it…” Evidence from her Expo report showed that the information from the Internet was supplemented by further information from *Human & Ocular Anatomy* (p. 116). She corroborated on this during the interview: “Well, the research into [the] other methods came from the Internet. The research on the actual stable point in the eye was…from a doctor…of optometry…” Interpreting information “include cross–referencing information in books…” (DoE, 2002, p. 14). These two sets of information might have set the stage for her cross–referencing skills. Moreover, So (2003) emphasised the importance of acknowledging sources in students’ work related to science projects. Gertrude was able to acknowledge sources of help in, for example, the doctor who provided the camera, and his expertise in relation to the most stable areas of the eye (p. 115).

Gertrude was also able to gather and make sense of relevant information. Her Expo report showed that the electronic equipment used included the Fundus camera and a laptop. Evidence from the report suggested that this sophisticated equipment was used to measure, gather and/or process systematic data on the unique properties of the randomly selected subjects' eyes:

> The Fundus camera was used to take photographs of the back of the eye. A random selection of people was chosen in order to take the measurements…The photographs were loaded onto the laptop. The program called "Paint" found on all Microsoft Windows programs was used.

In short, the subsequent functional data that was ready to be interpreted was the result of empirical observations embedded in systematic steps which involved loading the subjects' pictures into the laptop, and processing the information in an organised and logical manner to produce a unique fundus database. Gertrude was able to compare and discuss her the data from the database under a section "Interpretation" in her Expo report. The report showed that she noted that the readings related Fundus ID numbers were different. She elaborated: "The final mathematical formula resulted from both formulas' being the variable and accurate columns produced different answers for every Fundus photograph".

As referred to elsewhere (pp. 166-167), Gertrude could also engage in proper representation of her data and information. Tabular format was used predominantly because it was the ideal method to provide clear, compact and concise information about Fundus photographs' varying measurements. Although she: (a) claimed that graphs were not suitable for her Expo project, and (b) did not mention the photos and the eye model during the interview, these pictorial and mathematical forms were clearly useful. For instance, the colourful photos of the internal parts of human eyes and the eye model helped suitable audience to gain a better understanding of the eye, the fundus, including its location in the eye.

As referred to elsewhere (p. 162), Gertrude's investigation was a combination of two types of investigations – pattern seeking that involved a survey, and making things. Analysis of the interview indicated that she was not able to report how she analysed her data. She answered:

> I typed it up from the Internet like re–word it, printed out my sources, as well as what I'd in the Internet and then I re–wrote the important stuff in my own words. And, I supplied…the research down the computer in my project so that they know exactly

where I got it from.

Despite being challenged during the interview, analysis of her Expo report showed that Gertrude actually used program in "Paint" to analyse her data. Evidence from the report showed that she was able to use a suitable programme. She said about the programme: "It had a scale (in pixels) to take accurate measurements in a horizontal and vertical line [or distances]". It should be noted that she had to measure four distances in each photograph whose measurements were coded A, B, 1.C and 2.C. The measurements were essential in computing the subjects' Fundus ID numbers through utilisation of the mathematical formulae. The subsequent outcomes of the analyses were rational conclusions (pp. 164-165). For example, she concluded that we are unique individuals and so is our eyes' Fundi. It should also be noted that Gertrude suggested a more improved computer programme that would create highly accurate measurements (p. 164).

Gertrude also shared with me her estimations that were based on what she already knew (**predicting**). She mentioned issues related, for example, to genetics. Her established fundus database and researched properties of fundi should have enabled her to make a prediction on fundi for people of, for instance, identical genetic makeup (i.e., twins), and of different ethic groups, age, and gender. However, as written in the questionnaire, she predicted: "that everyone has an eye"; "that every position in an eye is found in any person"; and "finger prints are unreliable". Despite being challenged in relation to the skill, it could be concluded based on analysis of the interview, that her "predictions" were rooted from knowledge gained from the Internet while she sought to find in the Web how her "method [of identifying a person] was better than theirs [other researchers] or how it could be improved to be better than theirs".

Analysis of her Expo report also revealed that she was able to formulate **hypotheses**. Analysis of the questionnaire showed that she thought, "every person must be different and that every person can be used to identify with [i.e., everyone can be identified based upon their intrinsic traits]". Hence – based on evidence from her Expo report – the following was the expected outcome of her experiments or investigation (Padilla, 1990): "Having a test group of 500, the Fundus identification numbers for the complete sample test group would all be different".

She was able to reason that if "…no two photographs (unless [from] the same individual) of the Fundus have the same measurements…[then, that qualifies]…Fundus photograph as a method of identifying a person". She added: "However, any result above 80% success rate could be used as a helping aid in identifying a person". Analysis of the questionnaire showed that, similar to her predictions, knowledge underlying her proficiency in hypothesising was rooted in the Internet–based research methods of biometric identification. She discovered that "There're 8 present methods of biometric identification…and there're about another 10 emerging methods that haven't been completely researched".

It is considered that before one formulate a hypothesis about a situation, one should think about a research problem, which is usually framed as a question (p. 135). Gertrude also engaged in **raising questions** related to a better way of identifying a person in the future. The interview showed that the following were the questions she was able to formulate, which guided her investigation in which she aimed "to determine whether a photograph of the back of the eye could be used to identify a person": "What'd happen if the person is dead? What'd happen if you have twins or triplets…" She added: "…like stuff like researching to see if it's done already, well that's also another big research point".

We also conversed about how she went about starting her project. It was important that Gertrude started by defining her problem (see Devereux, 2000). Such a research problem may be framed as a question (Shuttleworth, 2004). Analysis of her Expo report showed that her research was the result of an observation based on her diabetic grandfather's Fundus photograph. She continued: "This photograph caused me to *ask the question* as to whether all Fundi look the same" (emphasis added). Analysis of the questionnaire showed that she formulated more questions she "needed answers to [regarding 'Fundi']". The implication is that, at the beginning (i.e., **planning science investigations**), Gertrude was able to ask a vague question and eventually made it into a testable prediction that Fundi do not look the same.

It should also be noted that she had to plan what variables to measure and how to measure them, knowing how to improve the accuracy and validity of the measurements, making inferences from results, and evaluating her plan for a fair test. As referred to elsewhere (p. 162), she had designed her investigation. Analysis of the report showed that in order to answer her questions, she planned surveys to measure her sample's Fundus photographs using mathematical formulae, which would "be used to create a Fundus Identification number [for each of her subjects]". Gertrude emphasised: "Well, I did the project myself, I knew exactly what I was doing". Indeed, her report showed that she was aware of what variables to be measured (i.e., horizontal or vertical distances between certain internal structures of the eye), and that she needed a table to record the subsequent values (i.e., "VARIABLE" and "ACCURATE") needed come up with each person's Fundus identification number. As stated elsewhere (p. 165), she was aware that she would have to repeat and check her measurements and select suitable measuring techniques to establish trustworthiness in her data. Furthermore, analysis of the interview showed that she had proficiency in noting "stuff you kind of just ignore to even put in your project. Just stuff that's should just be constant anyway [and are part of fair testing]". Evidence from the interview showed that the "stuff" (extraneous variables) included providing a room with ideal conditions (e.g., "the same lightness" [her example]) and ensuring that "[nobody] had their eyes dilated [i.e., she did not use drugs essential for dilating eye pupil for better fundus examination]" as well as "no racial discrimination, [or] age discrimination".

In order to get a picture of how Gertrude developed the skill **conducting the investigations**, I asked her the following question: *What are many things you did as you carried out the practical part of your investigation?* According to DoE (2002), while controlling interfering variables, Gertrude should have measured the variables, recorded data, interpreted data to make findings, and reported her work in qualitative and quantitative terms.

Analysis of the interview showed that Gertrude meticulously followed these procedures to ensure the trustworthiness of her findings:

- *Setting*: "Every single picture was taken in the same room…and the light in that room was the same lightness". She also asserted that she kept constant the position of the machine and the chair. Hence, nobody's photo was taken at a different angle.
- *Selection of participants*: Every body was accommodated. Analysis of the report revealed that "a random selection of people was chosen".
- *Sophisticated equipment*: She used a "non–mydriatic camera", which explains why she emphasised that the participants' eyes were not dilated.

Analysis of the report showed that she meticulously followed procedures (evidence derived from method section) now for the collection and recording of her observations. The analysis showed that she was able to:

a) Use "Paint" programme to "take accurate measurements in a horizontal and vertical line".
b) Record the measurements of each image in tabular form (i.e., 1.C and 2.C; Vertical distances associated with macula and central retinal vein/its branch; 402 and 350 [quantities to be used in the mathematical formulae together with quantities from A and B distances]).

The steps a) and b) were essential for her to interpret her data. For example, analysis of her Expo report showed that the subsequent columns (after computing the measurements using final mathematical formula) "produced different answers for every Fundus photograph". Hence, she was able to report her findings in both qualitative and quantitative terms. For example, analysis of her Expo report showed that she was able to report that – based on the evidence collected from Fundus photography – "a model using Fundus photography can be developed to determine the identity of a person". She formulated an eight–column table (contained, for instance, quantities of the four distance measured and the corresponding computed Fundus ID numbers) to communicate her findings in quantitative form. Evidence from the interview (and the questionnaire) showed that this practical part of her investigation involved analysing data (both at pilot stage and during the main study [pp. 162-163]), as she also ensured that there were no errors or omissions, just to ensure that her Expo project was "proveless" (i.e., impeccable):

> Well, I kept analysing…my photographs when I got more of them, 'cause I couldn't take all in one day. And, [I] kept…taking more and analysing them and seeing if I got different results, 'cause if I got one of the same results…it wouldn't have…my project wouldn't have worked as well. You know, it would've…there would've been like potholes and stuff in it. So, I was just checking up making sure everything's right…just stuff that you make sure your project's proveless.

Life Sciences knowledge

Evidence from Gertrude's triangulated data provided Life Sciences knowledge she had developed in the Expo in which she investigated contactless Biometric Technologies. Analyses of the data showed that the process of the Expo investigation and the scientific skills she developed formed the basis for the development of biotechnological knowledge around her "invention" – a new method of identifying a person. Tables 4.3a and 4.3b below present summarised descriptions of the knowledge she developed.

Table 4.3a

Gertrude's developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 1: Scientific Inquiry and Problem–solving Skills (for Grade 10)

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Identifying and questioning phenomena and planning an investigation	Generating and questioning "hypotheses based on identified phenomena for situations involving more than one variable" (DoE, 2003b, p. 17) – for Grade 12	The fact that Gertrude's work was a "research project never done before [by a high school student in South Africa] and a new method of contactless Biometric Identification" implies that she had to adopt a more complex and advanced approach in, for instance, planning her investigation. Firstly, it should be noted that Gertrude had proficiency in observing characteristics of her diabetic grandfather's Fundus photograph and "question as to whether all fundi look the same". Her Expo report showed that in order to answer her question, she sought to determine whether a photograph of the back of the eye could be used to identify a person. Secondly, she was able to relate her hypothesis that "the Fundus numbers for the complete sample test group would be different" to the fact that people have intrinsic physical traits that are unique. She authenticated this in her questionnaire: "[My hypothesis is] that every person must be different and that every person can be used to identify with [using a mathematical formulae]".	Gertrude was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.
	Designing "tests and/or surveys to investigate these variables" (DoE, 2003b, p. 17) – for Grade 12	Gertrude's investigation required pattern seeking that included making things. Her Expo report showed that she had proficiency in designing tests and surveys to investigate components of each participant's eye. She used advanced mathematical formulas with her participants to investigate whether the measured distances in the eye that constitute each participant's Fundus ID number were different.	

Table 4.3a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Identifying and questioning phenomena and planning an investigation	Evaluating “the experimental design” (DoE, 2003b, p. 17) – for Grade 12	Gertrude revealed her thoughts about her Expo project: “I think I achieved more than…what I intended on…” She also thought her assumptions were met: “I took photographs and analysed them and found that every person was different”. However, she noticed the need to refine her experimental design in terms of, for instance, her sample and an analytical tool. She reported that she should have started by: ▪ Increasing her “sample size by double”. ▪ “Getting a computer program developed”. Her Expo report showed that she recognised that there was a need to update method of taking measurements. One of “the questionable factors” of her investigation included “inaccuracy in taking the measurements”. She suggested development of specialised equipment and *computer programmes* to take measurements automatically. ▪ “Speaking to mathematics teachers” (probably about the computer programme that needed to be developed and the associated mathematical formulae).	Gertrude was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.
2. Conducting an investigation by collecting and manipulating data	Systematically and accurately collect data using selected instruments and/or techniques (DoE, 2003b) – for Grade 11	Gertrude utilised a rare and expensive Topcon Fundus camera and mathematical formulas to investigate her participants’ Fundi as she conducted her surveys. She could use it as she “…approached an Optometrist who owns a Fundus camera” for help. Gertrude also collected relevant information related to the biological phenomenon investigated from Internet and a book. Accurate results were essential. Hence, she used a programme in “Paint”, which enabled her take accurate measurements of her subjects in order to compute the subjects’ Fundus ID numbers through utilisation of the mathematical formulae. She established a database, which was then transferred to her Expo report in which it was presented in tabular form.	Gertrude was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.

Table 4.3a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Conducting an investigation by collecting and manipulating data	Selection of "a type of display that communicates the data effectively" (DoE, 2003b, p. 21) – for Grade 11	Gertrude utilised a poster to summarise and display all the results and plans to communicate her science information in mathematical and pictorial forms as part of the Expo exhibition. She also had a report to provide a more detailed account of her project for the specific audience.	Gertrude was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.
3. Analysing, synthesising, evaluating data and communicating findings.	Critically analysing, reflecting on and evaluating the findings (DoE, 2003b) – for Grade 12	Gertrude was aware of the importance of analysing, reflecting on and evaluating her findings: "I mean, in any scientific investigation you've to come up with questions that could may be criticise or doubt your project in some manner…" The basis of her evaluation was "inaccuracy in taking the measurements", which might have had an impact on her findings. Indeed, she answered during the interview: "…I'd to obviously redo some of them until they were accurate. I'm not saying that every single one of my measurements are accurate. That's the reason why I've got two formulas".	Gertrude was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.
	Explaining "patterns in the data in terms of knowledge" (DoE, 2003b, p. 23) – for Grade 12	It should be noted that Gertrude had a database in which she had Fundus Identity Numbers of her subjects. These were printed in a sheet. She was able to explain patterns in the data using knowledge developed. For instance, these were two of the "facts" she learnt: (a) measurements had to be horizontal and vertical distances of specific parts in the eye, which are taken using any Fundus cameras; and (b) the measurements are used in formulae named variable and accurate to finally produce a person's identity number. She used this knowledge to explain patterns: "As [it] can be seen from the result sheets…using both the variable and accurate formulas…[showed] no answers that were equal within the sample of 500 fundus photographs". She added: "If investigated over many more people it is possible to get the same results".	

Table 4.3a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
3. Analysing, synthesising, evaluating data and communicating findings.	Providing conclusions "that show awareness of uncertainty in data" (DoE, 2003b, p. 23) – for Grade 12	Gertrude was aware that "results are [however] unknown for people who are not living". Moreover, her investigation did not encompass tests "on identical twins, triplets, etc…[and that] age and race have not been taken into consideration". Hence, she concluded that although her contactless biometric identification can be used to identify people, and it is more advantageous over other methods, there are still more developments that had to be made.	Gertrude was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.
	Suggesting specific changes "that would improve the technique used" (DoE, 2003b, p. 23) – for Grade 12	Gertrude suggested, in her Expo report, a specialised equipment and computer programmes that will take measurement automatically to produce impeccable findings.	

Table 4.3b

Gertrude's developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 2: Construction and Application of Life Sciences Knowledge (for Grade 10)

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Accessing knowledge	Use of "various methods and sources to access information" (DoE, 2003b, p. 25) – Grade 11	Gertrude was able to access relevant information on methods of biometric identification by predominantly using Internet: "I used the Internet to research other methods of biometric identification…like present methods and emerging methods". The information from the Internet was supplemented by information from *Human & Ocular Anatomy*.	Gertrude was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.

Table 4.3b continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Interpreting and making meaning of knowledge in Life Sciences	Identification, description and explanation of "concepts, principles, laws, theories and models by illustrating relationships" (DoE, 2003b, p. 25) – Grade 11	Gertrude's work showed that she developed the scientific concept of utilising digital retinal images from a specialised camera for biometric identification. She used the sources in 1. above to: provide examples of biometric identification; briefly describe "the basic elements of the biometric system"; provide "facts concerning biometric identification"; illustrate the emerging biometric techniques, and state and illustrate "biometric application"; and provide and explain "terminology" used in biometric identification (e.g., Fundus and macula [her examples]), in her quest to illustrate relationship between human digital retinal images and biometric identification.	Gertrude was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.
	Evaluation of "concepts, principles, laws, theories and models" (DoE, 2003b, p. 25) – Grade 11	Gertrude discovered that "there're 8 present methods of biometric identification…and there're about another 10 emerging methods that haven't been completely researched". Then she evaluated the methods and discovered that hers was the best: "I think my method's like very good 'cause it can be used in small children, which not the other methods can be". She reasoned now using fingerprints: If you've scrape on your finger, sore on your finger…they can't take fingerprints, which obviously makes it very unreliable 'cause, I mean, criminals scrape off their fingerprints nowadays so that they can't get caught by their fingerprints. They need a method that you can't change. It should be noted again that Gertrude was also aware that there is a further need for developing and improving the way digital retinal images can be measured and analysed.	

Table 4.3b continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
3. Showing an understanding of the application of Life Sciences Knowledge in everyday life.	Evaluation and presentation "of an application of Life Sciences knowledge" (DoE, 2003b, p. 27) – Grade 12	Gertrude evaluated contact biometric technologies and contactless biometric technologies. Then she conducted a survey on the latter (i.e., retinal scan [her example]), and subsequently compiled an Expo report to present a new knowledge she developed in relation to utilisation of digital retinal images to identify people, including lost children. Her understanding of the application of biometric technologies today was also shown in her conclusion that the Fundus identification number can be used together with other methods, and that it can be applicable in drivers' licenses, people's credit cards or security identification cards.	Gertrude was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.

Felicia

Felicia stated reasons she thought would explain what made her think she could do the project. Evidence from the questionnaire showed two attributes she felt contributed to her proficiency:

- "I have done this 'Expo experience' before so I now…have the skills/ability to complete an expo project". Indeed her diary showed that this was her third participation in Expos.
- "I also have confidence in myself so that if I put effort into it, anything can be achieved".

In short, Felicia thought that both her *competence* (developed from previous Expo experience) and her *problem solving attitude* (i.e., confidence in self) were enough for her to carry out a project of that magnitude.

Despite the stated attributes, analysis of the interview showed that her Expo project proved to be a challenge. The analysis showed that the challenges she encountered involved indifference of some of the participants (she called them patients), and managing and conducting the project itself. She answered:

> Communicating with people who are very apathetic towards anything you're doing [laughing quietly]. Yes. No, 'cause it's like…if it doesn't affect them, why should I bother. That's the attitude of most. So…you gotta say, OK, I'm doing this project, here're the reasons, here's the data, this is why I'm doing it, for what. And, [you] gotta

> explain it to them and make sure they understand. And, then you gotta keep going back…every couple days you gotta phone. Every week you gotta go there, and [you] gotta check up on what they're doing, how they're doing it, and managing and everything.

Felicia also had her own thoughts about what constitutes science/scientific investigation, which were based on her experiences with her current investigation (and probably her previous Expo experience). It should be noted that analyses of her Expo report (and the interview) showed that her investigation was a survey in which she investigated "usage *patterns* of hormone replacement therapy (HRT)" (emphasis added). Felicia also investigated the relationship between breast cancer and hormone usage *patterns*. Therefore, her investigation was categorised as pattern seeking. Her questionnaire showed that she thought her Expo project made her:-

1. Understand that:
   (a) "[Scientific investigation] takes a long time – need[s] proper organisation and management (of everything!)".
   (b) "[Scientific investigation] is a process – [it] start[s] with passion, ideas, background research; then develop[s] ideas and arrive[s] at conclusions which can be further interpreted".

In short, a scientific investigation requires impeccable execution, with not only passion and ideas and their subsequent development, but also understanding the associated scientific method.

2. Recognise the nature of science:
   a) "I gained knowledge regarding statistics, medical knowledge (HRT, menopause, breast <u>cancer</u>, etc.)" (emphasis in the original).
   b) "It is all complicated and with all science investigations you can come to various conclusions [therefore] it takes determination, interest, time!"

In summary, in science she had an opportunity to acquire relevant knowledge. However, she discovered that science is challenging, especially with its scientific investigations, whose outcomes may not necessarily be conclusive (as evident in her research findings compared to those of *Women's Health Initiative Study* [footnote 6, p. 109]) and therefore require positive scientific attitudes. She emphasised during the interview that one has to take his/her time and apply more effort in his/her investigation.

Science process skills

Felicia also reported the skills she thought she had learnt during her Expo project. Analysis of the questionnaire showed that there was one process skill she was able to report – **recording information**. She answered: "I always keep a log book – it helps me organise my time, write/put my thoughts on paper and help me to complete my project". I also examined the interview data for more process skills and/or other skills. The excerpt below shows that the process skill – recording information – also encompassed time management skill. It also shows that Felicia was aware that because a scientific investigation involves scientific processes, it (i.e., scientific investigation) is a process itself. It was thus no surprise that she was also aware that one should, for instance, understand **designing investigations** and **analysing investigations**:

> It is a process. You got to understand that. You can't just go from beginning to end, phew! There is your project. You…got to go through your aim. You got to know stuff about your area and explore ideas around it; decide on what you want to do; *go through the process of investigating*, if something doesn't work *go back, [and] change your variables a bit*. Yah, you got to like *take your time and put an effort in research*, yah (emphases added).

It should be noted that **designing investigations** and **analysing investigations**, which are part of the process skills she developed, were also connected to several conventional sets of scientific attitudes she developed. For instance:

- Scientists are logical and systematic (i.e., *one has to go through the process of investigation* [see the excerpt above]).
- They work hard and are persistent (i.e., *one has to take time and put effort in the research*).
- They are flexible and can critically reflect on their work (i.e., *one has to go back and change variables if something does not work*).

Felicia also showed critical–mindedness. For example, she consulted relevant expertise, such as doctors, for example, to gain background knowledge about aspects of HRT and breast cancer. Most importantly, she was able to challenge the validity of a publication of the *Women's Health Initiative Study,* as we shall discover in the next paragraph.

Felicia was able to identify biological phenomenon to be investigated. Analysis of her Expo report showed that she noticed that the publication of the *Women's Health*

Initiative Study made a controversial claim (footnote 6, p. 109) related to certain risks of HRT such as, for example, the increased risk of heart disease, thrombosis and breast cancer (her examples). She added in the completed questionnaire: “I knew that there would be a lot of controversy in the research – so I wanted to investigate it for myself”. Hence, in order to challenge the claim, she sought to “investigate the usage patterns of hormone replacement therapy (HRT) and then investigate the relationship between breast cancer and hormone usage patterns…using the programme[s] Graph Pad InStat and Graph Pad Prism” to carry out statistical analyses.

In the following paragraphs, I present Felicia’s descriptions of her process skills that were applicable to her study and were therefore utilised. She provided her own account of how she developed the **observing and comparing** skills. It should be noted that this process skill, according to the DoE (2002), is focused on “noting details of objects, organisms and events [in experiment–based setting]” (p. 13). Felicia’s observations were not experiments–based because she conducted a questionnaire–based survey. Consequently, similar to Gertrude’s case, Devereux’s (2000) criteria for evaluating this process skill were used (i.e., describing patterns and ordering and sequencing events). This criteria was also adopted in the next case study (i.e., Henry’s case).

Felicia’s Expo report showed that she administered a questionnaire to 260 “patients”. The report also provided descriptions of patterns drawn from the questionnaire data (see the bullets in the next page [i.e., p. 183]). Her interview data merely provided supplementary data – the basis for her observations: “I mainly *looked at the trends*…in the breast cancer group, sub–divided that to HRT and no HRT exposure…I looked at ages…mammograms…general families histories…all these correlational things…” (emphasis added). The interview data also provided an insight on how she *ordered and sequenced events* that made up her observations:

> I started with my general ideas. I spoke to people – oncologists, medical experts. Then, I applied for my ethical consent just to make sure it was all ethically sound. Then, I went to – for breast cancer group – I went to oncologist and people on that field, ‘cause it was all women. So, then for my control group, obviously I went to beauticians, hairdressers and women “in (higher) places”…then I did stats [statistical] analysis, so, I think it was like four months, yah…So, I looked at trends…and you can’t say, “Yes! That is the cause for breast cancer”. You got to say OK, this, this, this, can only increase your incidence chances, yah.

Analysis of the interview also showed that Felicia was confronted with some challenges in relation to the development of the observation skill. The analysis showed that the challenges included access–related problems, which proved time consuming; the ample data she collected; and carrying out statistical analyses. Nevertheless, analysis of the Expo report showed that she had proficiency in *describing patterns* drawn from the questionnaire data:

- "There was no significant trend to suggest that there is a significant association between HRT and increased risk of breast cancer". This implies that HRT usage does not necessarily lead to increased risk of breast cancer as asserted in the *Women's Health Initiative Study*.
- "There was no significant trend to suggest that a family history of breast cancer can significantly increase your own risk of developing breast cancer". This implies that people who have a family history of breast cancer are not necessarily prone to the condition.

The fact that Felicia's study was focused on a survey and statistical analyses of the questionnaire–based data showed that the development of the **measuring** skill was mainly focused on her proficiency in reading scales and using intermediate points between divisions on scales as she made attempts to represent her data in graphical forms. This further showed another limited compatibility between certain process skills stipulated in the DoE (2002) and survey–based investigations. Nevertheless, analysis of her Expo report (i.e., of the graphs and the associated explanations of the graphs) showed that she was particularly able to read scales.

It should be noted that there were virtually no quantities to measure in Felicia's projects apart from taking care of the scales. Hence, it was no surprise that she did not address the issue of accuracy and precision in measurements in terms of using appropriate scales on instruments used, but in relation to accuracy in deducing HRT and breast cancer trends:

> …looking at the breast cancer, the families' histories, 25% of all women have a breast cancer from history. So, it's across the board. So, it's quite a higher percentage, which means education awareness, mammograms, all of that…And, then when you look at the actual treatment of breast cancer, how you can back up and see if you're accurate in your data is, *one*, by looking at, OK, well so many percentage chemotherapy, and for chemotherapy so many must obviously have a certain treatment. So, you link it up and it did link. And *another way* of making sure it's accurate is when you sub–divide it into the groups, and you add up in your different sections they've to be equal, which they were.

As stated elsewhere (p. 130), description of representing data encompassed recording of information and data. Similarly, I decided to present the descriptions of Felicia's proficiency in **recording information** and **communicating science information** concurrently.

Felicia asserted that she developed skills in recording information (p. 181). Her Expo report showed that she was able to select suitable "forms" (DoE, 2002, pp. 13, 14) to represent her data and information in graphs and tables. Analysis of the report indicated that she firstly recorded all her "survey information into Excel spreadsheets". As evident from the completed questionnaire, she "used the Microsoft Excel programme to analyse/record data". The analysis of the report showed that in addition to prescribed written forms, such as sentences, she constructed graphs to record her information using Excel. She wrote: "I made graphs from this data using Excel and then proceeded to do statistical analysis [sic] on the data". Evidence from her Expo report further showed the other form in which she recorded information resulting from the statistical analyses – tabular format. For instance, she had constructed a "[table of] comparisons between the Without Breast Cancer population and the Breast Cancer population".

Despite evidence of her proficiency in recording information from her Expo report, analysis of the questionnaire showed that Felicia understood recording information as more related to a diary or journal rather than *representing her data and information* in, for instance, tabular form. Hence, a diary became the best form of recording information related to scheduled daily plans, as evident during the interview:

> [I used a] diary. Log book. [It enables]…you keep track [of what's happening]…it's like a daily planner. So, if you say, OK, on this day I'm gonna speak to this many contacts, because I've got about 30 contacts for my, for all my little surveys.

Analysis of the interview also showed that her perception of recording information (see the excerpt) subsequently affected her responses to the forms of recording information in terms of their complexity and easiness. Her responses to the easier forms of recording information were as follows:

Interviewer (I): OK. So, which forms of recording information were easier to do?

Felicia: Which forms of what?

I: You said you recorded…the information, isn't it [***Felicia***: Mm], to keep track [***Felicia***: Yah] of what was happening? So, did you use different forms [of recording information]? Which forms of recording that information were easier?

Felicia: No, all I did was I just wrote down and generally kept for myself like little memoirs of to do, to do, to do.

Analysis of the interview also showed that she selected suitable means to communicate her results with the fellow Expo participants, the public, and the judges. Her exhibition encompassed a poster and an Expo report: “[The exhibition included] basic board structure. So…you [also] write your report obviously. And, then you do your aim, hypothesis, methods, results, your graphs, everything on the board”.

Felicia’s Expo report contained vast amount of science information in pictorial and mathematical forms, and written forms. The interview also showed that she had proficiency in utilising a more sophisticated form of presenting the information – appendices. She elaborated on this: “But, then what I did was I took like all the surveys and the data sheets and the stats analyses and everything just goes on like in files [and] appendices it…” The appendices included “graphs [colourful bar charts] with short explanations” and Excel spreadsheets containing information on breast cancer and HRT and their respective control group information.

It should be noted that the tables were used predominantly when presenting the results in the Expo report. The tables were used together with descriptions and explanations to enable people visualise and understand the results of the statistical analyses conducted.

As stated elsewhere (p. 130), students may be better at working with tables than graphs. Hence, Felicia was asked to comment on the forms of data representation in terms of those that were easy to do and those that were challenging. Analysis of the interview showed that she had no problem working with both the graphs and the tables she utilised. After all, she had been introduced to these forms of data representation during her early primary school days. Her challenge was merely related to statistical analyses:

> OK. So, your basic graphs and tables are pretty easy to represent, so down on excel, you just got to know how to label it and things. We’ve done that like in Grade 4. That’s OK…what’s more challenging is basically just knowing that you got…when you’re comparing your data to get your p–value, you gotta make sure you got every single appropriate one in the columns to make sure it compares. You got to do a number of times to check on yourself. So…it always takes time.

In order to organise her recorded results (e.g., in tabular form), Felicia had to engage in **sorting and classifying** the information. Analysis of her Expo report indicated how she developed her classification skills through grouping her subjects in order to understand the relationship between HRT usage patterns and breast cancer through two sets of comparisons. She was able to select a suitable system of recording information in a table, in which she named one group of her subjects “With Breast Cancer”, “Without Breast Cancer”; and the other group “HRT” and “No HRT”.

Regardless of her proficiency in this skill as evident in her Expo report, analyses of the interview and the questionnaire showed that she was not able to report how she went about sorting and classifying her subjects. Evidence from the questionnaire showed that she did not understand the question related to this skill. Her shortcoming was evident in her perception of “scientific items/objects” (footnote 11, p. 131). For example, she commented about sorting and classifying her information: “I never used items per say, but I received research references (like magazines) from various doctors”. In the light of this statement, I probed her during the interview in order to address the misinterpretation:

Interviewer (I): How did you gather and manage scientific objects/items you used?
(It should be noted that in her case she worked with people with, for instance, breast cancer and no breast cancer. As expected, she had organised her data in terms of the people’s status in tabular form. She had to reproduce that here).
Felicia: What’re you referring to when you say scientific objects?
I: …for example, you can use people, you can use plants, whatever you use, you can group them, you can name them. So, how did you manage that?
Felicia: I only used like your basic computer programme, which was Excel and graph pad, which is a stats programme. So, it’s very easy to do that. I didn’t really use objects.
I: You didn’t group people? You didn’t…[***Felicia***: Uh–uh, uh–uh]. Not at all?
Felicia: Uh–uh, uh–uh, because it was retrospective. So, all the people I contacted they were just like the “middleman” or “woman”.

Felicia also made an attempt to create meaning and structure out of her data and information (**interpreting information**). The following criteria – which was used in the two previous cases that were experiment–based – were used in the survey–based cases (i.e., Gertrude and Henry) that include the current case:

- Gathering and making sense of data.
- Data representation.
- Analysing data and drawing conclusions.

It should be noted again that interpreting information also involves ability to search for relevant information (DoE, 2002). Felicia’s interview showed that the Internet, libraries and hospitals were the main sources of information she needed: “[I searched for relevant information from] Internet, libraries, [and] doctors' rooms…" She elaborated on the statement:

> OK. So, for breast cancer, I obvious[ly]…I went through like pamphlets…the doctors wanting rooms, they've always got pamphlets. So, I went around and collected those…on menopause, HRT. I've got…the *Women's Health Initiative Study*. I don't know if you know about that. That was a journal…And, I just referred to all different dictionaries, encyclopaedias.

These sets of information might have set the stage for her cross–referencing skills. Felicia was also expected to acknowledge sources of help (see So, 2003). As referred to elsewhere (pp. 110-111), the sources of help were human resources. These included her parents, different doctors (i.e., surgeons, oncologists, etc.), a professor from one of the South African universities, and one teacher at the regional Expo. Her Expo report showed that all the human resources used were acknowledged.

Felicia evidently had to make sense of the data and/or relevant information she had. Analysis of her Expo report showed that most of her raw data were gathered through a questionnaire–based survey. The implication is that she did not have to use sophisticated equipment to measure and/or collect data. Instead, in addition to gathering relevant background information from the Web, she was able to use computer software to process and analyse the data systematically "using the [statistical] programme Graph Pad InStat and Graph Pad Prism". Indeed, the analysis of the interview showed that she had experience of statistical programmes essential to analyse the data:

> Stats. All stats. So, because *I knew stats from last year [2006]*. All I did was like I took the programme, took the information and applied it to my data from this year. So, you get p–values and it's easier to compare that well (emphasis added).

Analysis of Felicia's Expo report also showed that her representation of data and information was succinct. For instance, in addition to written descriptions and Excel spreadsheets formulated, she was able to use tabular and graphical formats to record and represent her data. As referred to elsewhere (p. 184), the tables were used to record and present the results of the statistical analyses. For instance, p–values in the comparisons between: (b) people with and without breast cancer, and (b) HRT population group and non–HRT population group. This tabular format was therefore instrumental in providing data that could be used to construct graphs (i.e., bar charts). The subsequent colourful bar charts were used to present trends and comparisons regarding factors, such as each participant's family history (e.g., with HRT history; without HRT history) and diseases and conditions (e.g., breast cancer and diabetes). Felicia also had figures inserted in her Expo report to supplement written information on "how to do a Breast Self–Examination". In summary, Felicia used different conventional forms of representing data and information to supplement the written information.

Analysis of the interview showed that in order to analyse her data, and hence deduce a pattern from the data, she arranged and organised the data on breast cancer and HRT in different spreadsheets:

> …OK, so I…'cause I said…I compared it into two different ways – HRT exposure and breast cancer incidence – so, I had two different spreadsheets. So, I took all my data and I put it first onto separate – no breast cancer, breast cancer – [and I] took all data applied it. So, whoever had HRT exposure, put it in that and no HRT exposure, yah.

The subsequent outcomes of the analyses, in which she used Graph Pad InStat and Graph Pad Prism, and interpretation of data were rational conclusions and suggestions regarding utilisation of HRT. For instance, analysis of the report showed that her findings enabled her conclude that:

1) "The use of HRT is common in women across the city [of Cape Town]". Hence, "HRT will always be used by women". After all, the younger group in her study had higher percentage of exposure (her comment).
2) Though not statistically significant, "[in general] women without a history of breast cancer had a longer exposure to the hormones".
3) HRT had been used for its intended purpose – menopausal symptoms and osteoporosis. She substantiated this assertion by stating that "the indication that the majority of women gave for starting HRT was those exact two reasons [i.e., menopausal symptoms and osteoporosis]".
4) "The controversial Women's Health Initiative Study found certain risks of HRT that in reality are actually very small".
5) HRT utilisation does not necessarily lead to breast cancer and family history of breast cancer does not imply that one is automatically prone to breast cancer:
    a) "There was no significant trend to suggest that there is a significant association between HRT and increased risk of breast cancer".
    b) "There was no significant trend to suggest that a family history of breast cancer can significantly increase your own risk of developing cancer".

Analysis of the report also showed that Felicia provided the following suggestions:

- Based on her findings across the two sets of comparisons (pp. 185-186), she discovered that, in general, the use of oral contraception was low. Hence, she suggested that “people need to take better care of themselves as the risks [of STDs] are too high, especially in the present world we live in”.

- Felicia also discovered that a few women visit hospitals for mammograms. Hence, she suggested that “this should not be happening – especially today”.

Felicia also made an attempt to develop her proficiency in **predicting**. According to DoE (2002), “this skill includes predicting patterns from information [using prior knowledge gained through collected data and information, or previous experiences]” (p. 14). Analysis of the questionnaire showed that Felicia’s predictions were, on the contrary, based on the design of her study. She listed the predictions she made:

- “I made estimations as far as how many surveys I would be able to get, based on talking to people/doctors”.
- “I also made estimations on time management”
- “I made estimations as far as ethical consent granting i.e: how long it would take, how hard it is to get etc.”.

Felicia was also expected to show proficiency in making a *testable assumption* of a relationship between a manipulated variable and a responding variable, and the subsequent explanation for that relationship (DoE, 2002). However, because her investigation was a survey, her assumption was supposed to be based on “dependent variable and possible causal factors” (Watson *et al.*, 1999, p. 105). As expected, the *Women’s Health Initiative Study* formed the basis for prior knowledge essential for her to hypothesise. She wrote in her questionnaire: “There was controversy around HRT usage and I was interested in the *Women’s Health Initiative Study*’s research and what the media was saying. So, I presumed that what they said was right”. Evidence from the report showed that she made the following assumptions, which were based on the information regarding the controversy and, as such, led to her investigation:

- “Despite controversy regarding the use of hormone replacement therapy and incidence of cancer, especially breast cancer, inadequate information still exists in Cape Town”.
- Due to the negative propaganda by media about HRT, “there **may** be an increase in breast cancer associated with the use of HRT, and that people of post menopausal age are stopping hormone therapy” (emphasis in the original).

Her Expo report showed that, apart from deducing the relationship between breast cancer and HRT usage patterns, she looked at, for instance, "other illness, including, cancer, heart disease and family history *factors*" (emphasis added).

Similar to Gertrude, Felicia should have considered – before she formulated a hypothesis about a situation – a research problem, which is usually framed as a question (**raising questions about the situation**) (p. 135). Analysis of the interview showed that she "raised a lot [of questions around the key question]". She elaborated on the questions: "…the main one: whether HRT does or doesn't increase incidences of breast cancer 'cause that was my main aim. So, I researched a lot around that and just basically what menopause was, what HRT is".

I also wanted to find out whether she engaged in rewording the main question to make it scientifically testable. Surprisingly, her responses were inclined to the questionnaire's formulated questions rather than her research question(s), probably because she did not understand the question. She answered during the interview:

> …we [have] done questionnaires since like Grade 7. So, you make sure…obviously you look at how, if you were answering the questionnaire, what would…how would you understand it. So, you obviously you don't want them to write so much. So, you do like tick the box or circle appropriate answer. So, to make it easier, and then you box things to make it easier to read…big font.

Felicia was also asked to provide an account of how she went about starting her project that was categorised as pattern seeking. I analysed data from her Expo report, the questionnaire and the interview to extract evidence related to the basic components of **planning scientific investigation**, that is, rewording a vague question to make it into a testable prediction, identifying evidence needed in order to address the question, selecting suitable procedures to be used, fair testing, and evaluation of the plan.

Analyses of the three sets of data showed that she started her plan with research/background knowledge rather than a vague question essential to launch her investigation. However, because she could hypothesise, she was able to identify information to collect in order to test her hypothesis. For instance, analysis of her Expo report showed that she planned to investigate HRT usage patterns and then investigate the relationship between breast cancer and the HRT usage patterns. She also planned to "look at patients using HRT compared to those who were not" and "look at patients with breast cancer compared to a control population of people without breast cancer".

Analysis of her Expo report showed that she was also able to select suitable tools and procedures to be used in the investigation. Evidence from the report showed that she decided to use surveys: “I decided that I wanted to investigate these issues for myself and so I decided to collect surveys and analyze the data”. Analysis of the questionnaire showed that, in addition to the survey, her plan included ethical considerations regarding her “sensitive topic” in which “patient confidentiality was central”. She answered during the interview: “And, then…before I actually started, I obviously I’d to go through the whole ethical process”. Analysis of the questionnaire also revealed that she actually had time plan as well: “I also made estimations on time management”.

Furthermore, it should be noted that Felicia’s study was correlational, which implies that because she had to look at variables and causal factors, she had to account on how she made sure that her plan was free from errors or omissions. Analysis of the report showed that she planned her dependent variables around, for instance, frequency of breast cancer, and possible causal factors around, for example, HRT exposure, family history of breast cancer, oral contraception usage, and so on. Furthermore, analysis of her Expo report showed that her responses on fair testing were basically focused only on one extraneous variable – age. All women studied were “post menopausal and between the ages of 55 and 75”. In light of this, she wrote in her report: “The average age of the women without breast cancer was 62 and with breast cancer it was 63. This shows that *the age group was constant throughout the testing*” (emphasis added).

I also asked Felicia to tell me about how she carried out her investigations. Analysis of her Expo report (i.e., method section) showed that she had well thought out procedures in place for collection and recording of data. Analysis of the report showed that the following were the main steps in executing the investigation:

- **Research/background knowledge**: She “gathered research on Hormone Replacement Therapy and breast cancer”. Analysis of the questionnaire showed that “in order to gain background knowledge about aspects of the topic and to gain ideas on how to make it better”, she consulted various people with appropriate expertise, such as doctors. She also wrote in her Expo report: “I then consulted surgeons, gynecologists and oncologists regarding research and questionnaire information”.
- **Controlling variables**: It should be noted again that Felicia’s study was

correlational and therefore not experiment–based (i.e., framed on controlling many variables). Nevertheless, Felicia asserted that she made sure that there were no errors or omissions. Analysis of the interview showed that she had a control group (people without breast cancer) in beauticians, hairdressers, friends and family. It should be noted that she "consulted numerous doctors and hospital units in order to acquire a 'breast cancer population'". Analysis of the interview showed that the basis for fair testing in her study was age:

> So, if you…I obviously did women. And, then *I chose a specific age group, 55 to 75*. And, then obviously they all have to be over…in an age group, but they all have to had menopause or going through menopause, yah (emphasis added).

- **Data collection**: Felicia's study was based on a survey rather than experiments. Therefore, she only used a questionnaire to collect data.
- **Recording and analysing data**: Because she had to complete statistical analyses prior to interpreting her information, she utilised computer–based methods for organising, representing and manipulating data: "I recorded all my survey information into Excel spreadsheets". Furthermore, she used graphs and tables. In order to analyse her data, she classified the data into breast cancer and HRT and their respective control groups. She computed statistical analyses using the *programme* Graph Pad InStat and Graph Pad Prism in which she computed, for instance, two–tailed t– tests and p–values.

Life Sciences knowledge

Below (Tables 4.4a and 4.4b) are descriptions of, for example, the knowledge that the analyses of Felicia's three sets of data (i.e., the interview, the completed Expo and the questionnaire) showed she had developed in a novel context (Expo) in which she investigated HRT utilisation and breast cancer. The analyses showed that the process of the Expo investigation and the scientific skills she developed formed the basis for the development of her scientific understandings.

Henry

Similar to the previous cases, an introduction to Henry's case included his thoughts about his abilities to do the Expo project, the challenges he encountered, and his perception of science/scientific investigations.

Evidence from the questionnaire showed that his performance in class, particularly in

Biology and Physics, was the deciding factor regarding his proficiency in doing his Expo project. He authenticated this: “I thought that I am capable enough as my Biology and Physics marks are in the 80s”.

Table 4.4a

Felicia’s developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 1: Scientific Inquiry and Problem–solving Skills (for Grade 10)

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Identifying and questioning phenomena and planning an investigation	Generating and questioning “hypotheses based on identified phenomena for situations involving more than one variable” (DoE, 2003b, p. 17) – for Grade 12	Felicia’s Expo report revealed her more advanced approach in, for example, planning her investigation. Firstly, she was able to observe that there was a controversial claim of certain risks of hormone replacement therapy (HRT) utilisation in the *Women’s Health Initiative Study (WHIS)*. As a result, in order to challenge the claim, she had to explore and investigate relationship between breast cancer and HRT usage patterns using scientific skills. Secondly, she was able to relate the controversy to “inadequate information” in Cape Town. Furthermore, she assumed that the controversy led, for instance, to people of post menopausal age stopping hormone therapy. What was, however more sophisticated was her inclusion of ethical considerations as part of her hypotheses, as evident in her written responses in the questionnaire.	Felicia was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.
	Designing “tests and/or surveys to investigate these variables” (DoE, 2003b, p. 17) – for Grade 12	Felicia’s investigation required pattern seeking. Her Expo report showed that she had proficiency in designing surveys to investigate not only the usage patterns of HRT, but also the correlation between the HRT and non–HRT users and breast cancer.	

Table 4.4a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Identifying and questioning phenomena and planning an investigation	Evaluating "the experimental design" (DoE, 2003b, p. 17) – for Grade 12	Felicia thought she achieved what she did not intend to: "…I went with what the *WHIS* said – Yes, HRT does increase incidences of breast cancer. I said [that] and then proved them incorrect…" Felicia also noticed the need to refine her experimental design in terms of her sample and the duration of her investigation. She reported that she should: ▪ Increase her sample size by: "looking at people in different environments not just the hospitals". Consequently, she was hoping for "more surveys completed/case studies [and therefore] more data". ▪ Consider doing the study over a longer period of time.	Felicia was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.
2. Conducting an investigation by collecting and manipulating data	Systematically and accurately collect data using selected instruments and/or techniques (DoE, 2003) – for Grade 11	Felicia did not use equipment to collect data. She carried out surveys in which she utilised a questionnaire. Her interview showed that, in her quest to investigate the relationship between HRT and breast cancer, she used a control group made up of beauticians, hairdressers, friends and family. She also obtained information on patients from numerous doctors and hospital units. As expected, apart from human resources available, she could collect relevant information from pamphlets in hospitals. She also collected the information from journals (i.e., WHIS), Internet, and other relevant sources, as we shall discover later. Accurate answers were essential. The interview showed that the basis for fair testing in her study was age. She was aware that the participants might not give accurate answers with regard to age as this was, she maintained, a sensitive study. Hence, she raised two questions to address the potential problem: It was: *which year did you go through menopause?* and *how old were you?* Like, the one you could almost [say]…it wasn't necessary. But, in a way it was 'cause then you can back up your answer to make sure it was the same (emphases added). She added in her report: I did a retrospective study and due to relying on the patients to fill out the forms correctly – there may be problems with accuracy. But, because I used statistics to analyse data – I was still able to obtain interesting results.	Felicia was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.

Table 4.4a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Conducting an investigation by collecting and manipulating data	Selection of "a type of display that communicates the data effectively" (DoE, 2003b, p. 21)	Felicia combined all the results and plans, and utilised a poster to summarise and display all these to communicate her science information in mathematical and pictorial forms as part of the Expo exhibition. She also had a report to provide a more detailed account of her project for the specific audience.	Felicia was able to meet the AS for Grade 10.
3. Analysing, synthesising, evaluating data and communicating findings.	Compare data and construct meaning to explain findings (DoE, 2003b) – for Grade 11	Felicia's Expo report showed how she compared her data: "First I compared the data between the breast cancer and the control population groups. I then split the information again and compared the data between the HRT and no HRT population groups". In order to construct meaning out of her data she computed statistical analyses on the data utilising the programme Graph Pad InStat and Graph Pad Prism. As she obtained Means and p–values, her explanations were both qualitative and quantitative. For instance, she found that "55 people who developed breast cancer were on HRT (30%) compared to 21 people who were not exposed to hormones and still developed breast cancer (27%)". She wrote in her report to explain her findings: "This is not statistically significant and therefore I am suggesting that the increased risk is too small to see and I proved my hypothesis incorrect".	Felicia was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.
	Draw conclusions and recognise inconsistencies in the data (DoE, 2003b) – for Grade 11	Felicia's Expo report showed how she concluded that there is no correlation between HRT and an increased risk of breast cancer. Furthermore, there is no evidence to suggest that a person from a family with history of breast cancer has high risk of the cancer. Felicia did not show any inconsistencies discovered in the data. This was probably because she: (a) had no specific technique to be used to "check that data was 100% accurate", or (b) she already had measures in place to address possible inconsistencies in her data, for instance, in relation to menopausal age (see 2.).	

Table 4.4a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
3. Analysing, synthesising, evaluating data and communicating findings.	Assess the value of the experimental process and communicate findings (DoE, 2003b) – for Grade 11	It should be noted that Felicia's investigation was part of the projects that were submitted for Expos. She was able to describe the value of her survey and findings. For instance, she believed that her study could help put the potential risks of HRT utilisation into context. She continued: "My project can contribute to spreading awareness and help to educate women in this country".	Felicia was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.

Table 4.4b

Felicia's developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 2: Construction and Application of Life Sciences Knowledge (for Grade 10)

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Accessing knowledge	Use of "various methods and sources to access information" (DoE, 2003b, p. 25) – Grade 11	As referred to elsewhere (see 2.), Felicia conducted a research on oncology–oriented problem, and that she was able to access relevant information on this phenomenon. Her proficiency in this regard (i.e., accessing information) was evident in her ability to search background knowledge from Internet and/or collect information on HRT and breast cancer from sources that included expertise in the field (i.e., surgeons, gynecologists and oncologists). She also collected pamphlets, journals and had access to different dictionaries, encyclopaedias, books and magazines on HRT.	Felicia was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.

Table 4.4b continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Interpreting and making meaning of knowledge in Life Sciences	Identification, description and explanation of "concepts, principles, laws, theories and models by illustrating relationships" (DoE, 2003b, p. 25) – Grade 11	Felicia was aware of the importance of developing scientific/health concepts in her study: "And…[when] you speak, make sure you understand what the hell you're talking about when it comes to breast cancer and HRT and know the concepts well". Indeed, her Expo report revealed new knowledge acquired in which the key concepts that were developed – which were related to the health conditions and diseases (e.g., menopause, cancers, osteoporosis, breast cancer, etc.) – included HRT, side effects and symptoms, disease, treatment and so on. For example, the report showed that the new knowledge acquired included treatment of some of the symptoms of menopause through utilisation of HRT. She started by describing, in her report, menopause and the associated cessation of oestrogen and progesterone in the body. Then, she explained that by using HRT, those "hormones are replaced and they help to treat the symptoms of menopause…" It should be noted that because her investigation had to include the source and incidences of HRT–Breast cancer, she also looked at "other illnesses, including: cancer, heart disease and family history factors".	Felicia was able to meet the AS for Grade 11. She thus exceeded the standard for Grade 10 students.
	Evaluation of "concepts, principles, laws, theories and models" (DoE, 2003b, p. 25) – Grade 11	It should be noted that information from WHIS, and other sources that are already mentioned (e.g., in 1.) provided a springboard for her to evaluate different ideas on the correlation between HRT and breast cancer. Indeed, her diary also showed that she evaluated different articles and "clinical trials" obtained from the Internet on the phenomena investigated. She discovered that there were "no set conclusions…[and therefore, there was] a room for studies [i.e., more research] to take place". She also wrote in her report: "…I wanted to investigate these issues (i.e., different ideas on HRT/breast cancer) for myself and so I decided to collect surveys and analyse the data so that I could come up with my own conclusions".	

Table 4.4b continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
3. Showing an understanding of the application of Life Sciences Knowledge in everyday life.	Evaluation and presentation "of an application of Life Sciences knowledge" (DoE, 2003b, p. 27) – Grade 12	Felicia's Expo report further showed that she was able to illustrate the applicability of health sciences to everyday life. She presented some applications that might prove useful in, for example, awareness and prevention of diseases, such as breast cancer. Evidence in her report revealed the following examples: "Evidence from my projects suggests that women do not have increased risk from HRT, but as long as they are aware of potential risks then they should be fine"; "Breast cancer is common and early detection is vital"; and "mammography should be offered to all women and should be done frequently". Felicia went on to argue in her written report that contrary to the findings published in *Women's Health Initiative Study*, in reality the risks of HRT are very small.	Felicia was able to meet the AS for Grade 12. She thus exceeded the standard for Grade 10 students.

Analysis of the interview showed that Henry also experienced an unforeseen challenge regarding his investigation. The challenge was related to access. He elaborated during the interview:

> …probably…trying to get schools to answer the survey…'cause a lot of schools didn't want to…the one school…in fact…said no, you must go after Education Department if you can to do this…so it was pretty hard to get…schools to accept it 'cause…it's quite a hard thing to get…300 surveys answered...but…there were a few schools that were happy to do it…[I'm] pretty thankful for that…So, that's probably the hardest thing…

Henry also drew on his previous experiences of Expo participation to share with me his own views regarding what constitute scientific investigation. It should be noted that analysis of the interview showed that he had "been doing it [Expos] for the past three years" then. Furthermore, analyses of his Expo report, the questionnaire and the interview showed that his investigation was a survey in which he also explored some variables. As a result, I categorised the investigation as pattern seeking.

In the light of the information (i.e., regarding his experiences with Expos and the nature of his investigation), it was no surprise that his reflections on the investigations were embedded in the process of an investigation itself. For instance, analysis of the questionnaire showed that he thought his experience with Expo made him understand that "[scientific investigations] need to be conducted thoroughly and every possible angle needs to be covered". He elaborated further: "Everything needs checking/editing…Wording is very important…There are no shortcuts…" The implication was that his experiences made him realise that scientific investigations require impeccable execution.

Science process skills

Analysis of data from Henry's briefly completed questionnaire revealed no process skill he could have developed. The analysis showed that he only managed his time well as he persevered: "I managed the project by working continuously essentially using stamina, also by working in every time possible – time management". However, the interview shed a light on the possible science process skills he might have used. Analysis of the interview showed that he blended the scientific method and process skills. The process skills he used included **interpreting information** and **communicating science information**: "…I'd say…going out, investigating…then analysing [data] and then…just…typing it up and displaying the data. So…just…going…step by step".

As stated previously, he discovered that his work required commitment and meticulous approach to details. Consequently, it was no surprise that although he was not able to report process skills he used, in his completed questionnaire, he was aware that he had to possess attitudes synonymous with scientists to make his study a success. For instance, scientists work hard and are persistent. Analysis of the questionnaire had shown that he managed his Expo project by working continuously hard.

Similar to the other five cases, Henry was able to identify biological phenomenon to be investigated. He had past experience with the phenomenon – allergies: "I used to have a lot of allergies". He added in his Expo report: "I chose to do my science project on the subject of allergies as I have become aware of the significant impact which allergic diseases have on my age group [i.e., school students between the ages of 14 and 18 years (his example)]". Indeed, he noticed that most of his friends have asthma which hampered their participation in sports. Consequently, he sought to investigate allergies in three schools in Cape Town.

I now present the descriptions of activities Henry executed as he investigated this problem of allergies. He provided his own descriptions of how he made an attempt to develop the **observing and comparing** skills.

As referred to elsewhere (p. 164), it was important that Expo students show their abilities in *describing patterns* and *ordering and sequencing events* related to the phenomenon observed in survey–based investigations. Henry's investigation was a survey: "In order to obtain the results about allergens and their affect on high school learners, I have chosen a survey format", and he recruited 400 participants. Evidently, his observations were not experiment–based because he intended to do a questionnaire–based survey. Therefore, his proficiency in the skill encompassed ordering and sequencing events, describing patterns drawn from questionnaire–based data, and noting similarities and differences.

Henry gave a brief account of how he launched his observations prior to sorting out the patterns and comparisons. He answered during the interview: "…I did a typed survey. And…[I] gave it to the schools where teachers could hand it out to the pupils…so [that] they could…write that up…Stuff that are for a survey form". Analysis of the interview showed that he eventually looked at trends in the information from the completed questionnaires and carry out some comparison. He noticed that asthma was prevalent in Emerlo (footnote 4, p. 92) where there were factories, and that there was correlation between smoking and asthma. He elaborated:

> …most people in Emerlo had an asthma. Also, the pupils whose parents or siblings smoke in their households also had asthma. Most of those pupils had asthma. So, I found that the *similarities* were that…asthmatic people had…either a smoker or they lived in areas such as Emerlo where there was…like industry around…factories for refineries. So…I think that's… probably the biggest [*similarity*] (emphases added).

Analysis of the interview also showed that Henry's development of the skill(s) was challenging. The analysis of the interview showed that he was aware that he had to analyse his data in order to create meaning out of it. However, the analysis showed that in order to achieve this (i.e., analysis of his data), he had to sort and classifying different allergies first, but that "was pretty hard". He elaborated:

> …actually finding a way to…look at and compare the allergies because…everybody has different allergies. So, just…finding a way to group it…in order to analyse…it was pretty ha[rd]…'cause you've all this information, and to find a way to organise it, that was pretty difficult.

Nevertheless, this difficult task/challenge did not have an effect on his ability to *describe patterns* drawn from the questionnaire data. Analysis of his Expo report showed that he had proficiency in noting that:

1. "62% [of the participants] claimed that stress affected their allergies". This implies that he noted that more incidences of allergies were related to stress.

2. "32% of the allergy sample had worsened lifestyle due to allergies". The implication is that he noted that allergies correlated with lifestyle.
3. The environment was also a determining factor. Henry noted that Emerlo, which is an industrial area with plants that emit "terrible fumes", had "majority of asthma sufferers".
4. Firstly, "54% of the 400 had someone smoking in their household". Then, when he further analysed his data he discovered that smoking actually increased chances of allergy development:
   (a) 58% of the asthmatic patients had a cigarette smoker at home.
   (b) "56% of rhinitis related allergy sufferers also had someone smoking in their household".

Henry's research study – by virtue of being based on a survey and statistical analyses of the questionnaire–based data – implies that the development of **measuring** was limited. For example, it was solely on reading scales and using intermediate points between divisions on scales essential for creating graphs. Nevertheless, he thought he measured factors, such as age and amount of stress:

> …basically…probably just…age and the amount of…stress that caused the allergies and also the amounts…if they had a small effect, minor effect or bigger effect on the lifestyle of allergies. So, I just…wanted to see…just take a look at how much the allergies affected the lifestyle.

Furthermore, we conversed about the issue of accuracy and precision in measurements. Analysis of the interview showed that Henry's perception that measuring could be applicable, for example, to age had a significant influence on his response to the concepts of *accuracy* and *precision* in relation to measuring. The concepts were supposed to be described in terms of, for instance, the graphs' scales in his case. Instead, evidence showed that he thought accuracy and precision were associated with obtaining reliable data from the survey:

> It…really wasn't any way to actually see if they were precise. Well, basically you have to take the word of the person. Unfortunately…this is more…its kind of a social thing, you know, if it affects their lifestyle. So, there isn't really any way to have it accurate, and it depends on a person.

We also conversed about recording information and data during the interview. So (2003) had shown that this skill is synonymous with representing data. Similar to the previous cases, the descriptions of Henry's ability to **record information** and **communicate science information** will thus be presented concurrently.

Henry's Expo report showed that a database in Microsoft Access was pivotal in his recording information/results from the survey. Indeed, during the interview, he maintained that his recording included organising the data and systematically adding it to the database. He answered: “So…I kept track of it…just by…organising it and putting it in a database in a systematic manner”. Analysis of the report also showed that, in addition to prescribed written forms, such as sentences or “written paragraphs containing commentary on the results obtained”, the results were “displayed in table form, bar–graph, [and] pie–graph”. During the interview, he however did not mention these mathematical forms of representing data (i.e., the graphs and the table).

On that note, students may be better at working with tables than graphs (p. 130). As expected (he failed to recognise the role of graphs and tables in recording information), he was not able to report the forms of recording information that were easier to do and those that were challenging. Analysis of the interview showed that he thought organisation of his ample data (i.e., 400 surveys) “with actual paper” constituted what was easier to do. According to him, what proved a challenge was utilising *typed* or written forms to record the ample data evident in his survey results document. He elaborated:

> OK. The…probably the easier thing to do was to…just organise it…with the, with actual paper…to sort it out in allergies and no allergies type of thing. But, when…actually I’d to type it out…each little…field and that kind of thing, that was pretty challenging ‘cause I’d to go through everyone of the 400 surveys, and just continuously do it…

As stated elsewhere (p. 199), Henry thought he had also developed an ability to communicate science information. Analysis of the interview showed that his exhibition, which was influenced by “ideas from previous studies [i.e., medical journals]”, encompassed a “booklet” (i.e., Expo report) and “the board” (i.e., a poster), which was organised according to prescribed Expo standard (i.e., aim, hypothesis, etc.). These two basic elements – the “booklet” and “the board” – were elaborated upon during the interview:

> Well, I took a look at…ways that people have…displayed…their information and investigations…I looked at…some of the medical journals that I got from one of the professors. And, I just looked at…how they…look at the information and how they display it. So, I…firstly I made the booklet…typed everything out. I organised it…aim, hypothesis, method...and all that. And, then I made summaries and I…put them on the board. So, I…actually got the idea from previous studies.

Analyses of his Expo report and the supplementary report (i.e., Survey Results Report) also showed his proficiency in reporting both in written forms and in mathematical forms. Analyses of the two reports showed that he was able to use colourful bar charts as well as a table together with descriptions and explanations to enable people visualise and understand the results processed through Microsoft Access database. For instance, the Expo report, in particular, encompassed graphs with short explanations of the results as evident in graph of "prevalence of allergy groups amongst sample (%)".

I also asked Henry to tell me about the forms of communicating science information he used also hoping that he would state those that were simpler and easier to do and the ones that were sophisticated and challenging. Analysis of the interview showed that he had no problem with the forms he utilised. Nevertheless, he focused on the two major aspects of the exhibition (i.e., the Expo report and the poster) rather than in the elements of these major aspects, such as the different graphs used. He answered during the interview:

> Well, the hard part was making a summary of everything that I've…done. So…the board that everybody looks at, that was…pretty hard to make 'cause I'd to…look at the information that is necessary…and I'd to summarise all the information, which was quite hard because it was pretty a big study. So…the actual booklets…like the report book – that wasn't too difficult 'cause…you basically type everything. But, summarising it, that was challenging.

Evidence in the first excerpt in the previous page revealed that Henry also engaged in **sorting and classifying**. For example, he had "to sort it [information] out in allergies and no allergies" prior to recording and analysing it. Analysis of his Expo report showed that, in order to deduce patterns in relation to the common causes and correlations of allergies in Cape Town, he grouped allergies common to his subjects. The allergies were grouped into, for example, "Asthma", "Rhinitis", "Skin/Eczema", "Food allergies", "Insect bites" and "Chemical Intake".

His Expo report evidently showed that he was able to sort and classify data. Analyses of the interview and the questionnaire, however, showed that he was not able to reproduce the grouping system he applied in relation to the allergies. The analyses showed that he did not understand what was meant by "scientific items/objects" probably because he merely sorted out *data* related to common allergies *not* "[scientific] items" (DoE, 2002, p. 13). He wrote in the questionnaire: "I researched/interviewed professors/used my own logic to decide on scientific items/objects". As his was rather an ambiguous and/or incorrect response, I revisited the question during the interview. He answered: "…it really weren't…any scientific objects [to sort and classify because]…it's like a social kind of thing…" This implies that the development of sorting and classifying skills in terms of items, *may* be applicable in experiment–based investigations or fair testing (where objects and scientific items are commonly used) than surveys (where it is data that is mostly sorted out to deduce patterns).

As stated elsewhere (p. 199), Henry also asserted that he developed skills related to **interpreting information**. Indeed, analyses of the interview, the questionnaire and the Expo report showed that he actually made an attempt to create meaning and structure out of his information. Similar to the previous cases, I adopted So's (2003) criteria (p. 132) to evaluate Henry's proficiency in the skill.

Analyses of the interview and the report showed that medical experts were the main sources of various forms of information on allergies that might have set the stage for cross–referencing. Two Professors provided high level of expertise in relation to allergies (p. 119). Medical journals, pamphlets, books, websites and a relevant research poster were resources available as a result of his interaction with the experts. Furthermore, he had an access to some current scholarly magazines related to allergies, such as "Current Allergy & Clinical Immunology Magazine: March 2007", which was listed in his bibliography. He also had an opportunity to engage in "discussions on allergies" with one of the Professors. Henry was able to acknowledge these sources of help (i.e., the professors) as well. Among other people who were also acknowledged for their help were his father for, for example, proofreading some of the data; and two principals from two schools who granted him permission to conduct surveys on allergies.

Henry had proficiency in making sense of the data and/or relevant information he had. He only used sophisticated equipment in a computer to process and anlyse his data using a database in Microsoft Access. He did not use sophisticated equipment synonymous with experiments–based investigations because they are normally used to measure and/or collect data. Consequently, by looking at the patterns in his data, he was able to interpret the data collected. Analysis of the interview showed that he was able, for instance, to note that most people have not been tested for allergies; and that the students today are susceptible to allergies than their parents. He corroborated:

> …well I noticed that…there was…increased amount of people that…(a) didn't actually have allergy test. And, also that…[(b)] their parents…most pupil had allergies but their parents didn't…so there's a huge increase of pupils that have allergies now and their parents, you know, they were not as much. So, the generation today…is a lot more [prone to allergies].

Analysis of his Expo report shed further light on his interpretation of the data, which was essential for making comparisons and informed discussions related to the various allergies. For example, based on the patterns in his data, he noted that the most common allergy was “Rhinitis”, then “asthma”, “Food allergies”, “Skin/Eczema”, “Insects bites”, and finally “Chemical intake”.

Henry also used different forms of representing data and information. As stated elsewhere (p. 202), he predominantly used a table and graphs. Analysis of his additional Expo report – Survey Results Report – showed that the table was used to record and present, for instance, data on the group of allergies investigated, such as asthma. The result of this tabular format was clear, compact and concise information needed to portray data patterns, in written forms, between, for example, asthma and age, gender, stress, pets, flora location and so on. The colourful pie charts and bar charts, on the other hand, were used to portray trends and comparisons regarding gender and allergies (e.g., graph of allergies in males and females), as well as how common a particular allergy was in relation to the others (i.e., prevalence [in percentage] of allergy groups amongst the sample used).

It should be noted again that his scientific investigation was categorised as pattern seeking. Moreover, he was also developing his skills in utilisation of the computer programme in Microsoft Access because he had an experience with the programme during Information Technology class at school. He elaborated on the arrangement and analysis of his data:

> Well, Microsoft Access…it’s a programme where you can…enter all this information into…fields and data…And, when you have it there then you can…there’s a special type of…almost like a little programme into our thing, which we can do to investigate certain aspects. We actually learnt Microsoft Access at school in IT. So…it helped me with that. And, from there you can draw graphs and work out the percentages…

Analysis of Henry’s interview showed that the arrangement and analysis of his data proved useful in providing him with information he needed. He answered about the information he obtained: “…it gave me statistics, which were very important”. Analysis of his Expo report revealed that the statistics were important because they would enable him “understand whether family history, location, stress or other factors contribute in any way to the learners’ allergies and to what extent”. He added on the information obtained during the interview: “…it gave me ideas of…how…people felt about the allergies…it basically just…told me about…who has [allergies] who hasn’t…and the effect on their lifestyles and everything else”.

So (2003) showed that analysing data is part of interpreting information which is essential in making scientific explanations, making reasonable conclusions and suggestions. Analysis of Henry's Expo report showed that, in addition to being able to discuss his results, the arrangement and analysis of his data proved useful in enabling him to construct logical conclusions and suggestions. For example, the analysis of the report showed that the results enabled him conclude that:

1. **Stress affect allergies**:

    > Something we can conclude from this minor study is that stress is something that can affect allergies…as stress can cause heavy imbalances in the immune system…and allergies are caused by an imbalance or over compensation of immune system…the study also shows that stress has an exacerbating effect on allergies as during times of exams or school projects, allergies manifest themselves more significantly.

2. **Allergies affect lifestyle**: "The next bit of information I would like conclude is that…32% of the people with allergies complained that their lifestyle was affected by allergies…" Henry illustrated that people with allergic rhinitis complained about their lifestyle being changed because the outcome of the allergy – blockage of their noses – "effects their speaking and actually limit them in a certain way".
3. **Hazardous environment causes allergies**. Henry discovered that there were many incidences of asthma sufferers at Emerlo. He stated that "most people who lived in the area (allergies or none) said that they were exposed to fumes from the oil refineries and factories nearby". He added: "…one of the primary causes of asthma are fumes given off by factories".
4. **Compared to the industries, households with smokers are typical of a microenvironment that is hazardous**. Henry illustrated that higher percentages were noted of incidences of Asthma and rhinitis in households with smokers.

Henry also suggested that "the problem of allergies should be addressed holistically". He illustrated in his Expo report that with respect to preventative measures and predisposition to allergies, people should seek "adequate treatment, focus on healthy diet, seek help when stress levels [rise] and endeavour to maintain a clean and friendly environment".

When asked about predictions he made, analysis of Henry's questionnaire showed that he was able to make estimations about one of the allergies he categorised – "Rhinitis". He authenticated this: "[I predicted that] Rhitis [sic] would be the most common allergy…" Analysis of the interview showed that his experience enabled him make proper estimations (i.e., **predicting**): "Well…I used to have a lot of allergies…You see it everyday…you don't actually notice it, but it's really a pretty big thing…it's quite limiting".

Based on the findings in Henry's Expo report, he had proficiency in **hypothesising**. For instance, he assumed that seasonal rhinitis (hay fever) would be the commonest of allergies amongst his age group. His Expo report showed that he was able to give reasons for his testable assumption using prior knowledge: "I assume this because almost everyone I know has a reaction to dust or pollen". Analysis of the report further revealed his proficiency in utilising prior knowledge as the basis for his assumptions. Firstly, analysis of the report showed that he assumed that Emerlo would have high incidences of asthma. The analysis showed that he knew that "fumes from factories and industries, which produce dangerous toxins, can increase the risk of asthma". Hence, because "Emerlo is in close proximity to the refineries and factories", he thought that it would "lead to an increase of allergies".

Despite his abilities to hypothesise, as indicated in his Expo report, analysis of the questionnaire revealed that Henry was either not able to state his hypothesis when asked to or he did not understand the question: *What presumptions did you make which led to your investigation?* He simply wrote: "I presumed that their [sic] was a basic need to know about allergies and what causes/affects/relates to them".

It should be noted that Henry was expected to have pondered over a research problem before he formulated the hypotheses. Such a research problem is usually framed as a question (**raising questions about the situation**) (p. 135). Analysis of his Expo report showed that he had both empirically– and theory–based questions that he raised around allergies. Analysis of the report showed that the questions included "what the different types of allergies are, what causes them, and how people get them". Henry added during the interview: "OK…[I asked]…what are allergies".

I also wanted to find out whether he was engaged in rewording the main question to make it scientifically testable (DoE, 2002). Analysis of the interview showed that he was not able to describe how he worked on the main question. His understanding of the question – *What did you do to ensure that those question(s) you raised could be answered through scientific investigation* – was inclined to "research" and formulated questions of the survey–based questionnaire rather than the research question(s) he raised:

> …that was…a research. And, I also when I went to see the professor – Professor Lewis

> – I gave him a copy of the survey that I'd ask the pupils. And he just read through [it, and]…he said…take out this, you could possibly add on this…

Henry also provided a brief description of how he went about starting his investigation (**planning scientific investigation**). Analyses of his Expo report showed that he started his plan with aim and the hypotheses prior to the survey, rather than a research question normally recommended to launch an investigation (Watson & James, 2004; DoE, 2002). Analysis of the report showed that he had proficiency in identifying information to be collected in order to test his hypotheses. For example, he planned to investigate causes and effects of allergies among high school students. He stated in his Expo report: "The survey form contains 18 questions which are designed to give a broad spectrum of *cause, correlations*, *effects* of allergies of high school learners" (emphases added).

Analysis of the interview showed that his research plan also involved a pilot study and the main study:

> …I started at…the school…I made [as a pilot study]…50 surveys and I handed out to the school – to Protea High School…to get a small overview of…the results that I could get. And, then I…looked at the information and I looked at the questions that I'd asked and I removed some…then I added…one or two. And, then I did [during the main study] the other 350 at…the other schools.

Analysis of the Expo report showed that Henry could also select suitable tools and procedures to be used in the investigation. The analysis showed that he decided to use surveys: "In order to obtain the results about allergens and their effect on high school learners, I have chosen a survey format [in which a questionnaire was utilised]".

As a survey involves dependent variable and possible causal factors (p. 189), I asked Henry about how he intended to address the issue of fair testing. Even though variables or causal factors were not stated in the Expo report, analysis of the Survey Results Report showed that he had dependent variables (i.e., frequency of asthma) and possible causal factors (i.e., location, parents smoke, etc.) in place. Analysis of the Expo report showed that his investigation was focused on high school students "between the ages 14 to 18 years" (extraneous variable). Hence, it was no surprise that he stated that to ensure a fair test he provided "everybody the same survey". He continued: "You know, just everybody has the same…everybody answers it as they can, so, yah".

I also asked Henry about the many things he did as *he carried out* the practical part of his investigation (**conducting the investigations**). I expected that he would demonstrate his proficiency in this skill by collecting complete and relevant data to study relationships between a variable and causal factors, "[provide an account of meticulous procedures regarding collection and] recording of data, interpreting data to make findings, and reporting in qualitative and quantitative terms" (DoE, 2002, p. 14).

The report showed that he collected data related to factors, such as "family history [of allergies]", "stress", "location [of the learners' homes]" "medication [they use]", "food [they eat]", to study how these factors "or other factors contribute in any way to the learners' allergies and to what extent". Analysis of the interview showed that the interviews he conducted and the survey in which he administered the questionnaire were considered the main aspects of conducting the investigation: "I'd just say…the interviews and just going to the schools to hand out the surveys".

Analysis of Expo report further showed that he used computer programmes as part of the sophisticated and efficient methods of organising and representing his data in a table and graphs to enable him interpret his data and then communicate his findings.

Life Sciences knowledge

Below (Tables 4.5a and 4.5b) are descriptions of, *inter alia*, the knowledge that the analyses of Henry's three sets of data showed he had developed. Similar to the other two students from Protea High School, analyses showed that the process of the Expo investigation and the scientific skills he developed formed the basis for the development of his scientific understandings in relation to allergies in high school students.

Chapter summary

In this chapter I have presented and analysed triangulated data on the development of scientific skills and Life Sciences knowledge, which was obtained from five cases framed on school students in the Western Cape. Also included were the students' biographies. In the next chapter (i.e., Chapter 5), I will now discuss the subsequent results. This will be done in correlation with research findings of previous pertinent studies, the thrust of the South African science curricula, and the context of Expo programme.

Table 4.5a

Henry's developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 1: Scientific Inquiry and Problem–solving Skills (for Grade 10)

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Identifying and questioning phenomena and planning an investigation	Generating and questioning "hypotheses based on identified phenomena for situations involving more than one variable" (DoE, 2003b, p. 17) – for Grade 12	Similar to the other two students from Protea High School, Henry's Expo report revealed that he also adopted a more advanced approach in planning his investigation. Firstly, he was able to note that "in Cape Town many learners face the problem of allergies resulting in respiratory ailments and skin conditions". His Expo report showed that the problem of allergies inconvenienced the students in their everyday life and therefore he sought to "try to investigate what the common causes and correlations of these allergies are in a [sic] Cape Town high schools". Secondly, he was able to hypothesise that the problem of allergies could be linked to hay fever, stress, smoking and fumes from factories and industries as well as gender and age.	Henry was able to meet the AS for Grade 12. He thus exceeded the standard for Grade 10 students.
	Designing "tests and/or surveys to investigate these variables" (DoE, 2003b, p. 17) – for Grade 12	Henry's investigation required pattern seeking. His Expo report showed that he had proficiency in designing surveys essential to compute statistical correlations that might enable him "understand whether family history, location, stress or other factors contribute in any way to the learners' allergies and to what extent".	
	Evaluating "the experimental design" (DoE, 2003b, p. 17) – for Grade 12	Henry's questionnaire showed that he believed his research design, especially with regard to his sample size, was satisfactory: "I don't believe there is much more I could have done i.e. 400 surveys were enough". However, he noticed the need to refine the design. According to him, he should have adopted a more rigorous approach encompassing a smaller sample with actual allergy tests essential to authenticate his participants' questionnaire–based assertions with regard to their allergies.	

Table 4.5a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Conducting an investigation by collecting and manipulating data	Systematically and accurately collect data using selected instruments and/or techniques (DoE, 2003b) – for Grade 11	Similar to Felicia, Henry did not use equipment to collect data. A questionnaire was instrumental in the surveys he conducted. In his quest to investigate possible sources of different allergies, he used high school students. He collected relevant information on the possible causes of allergies from pamphlets, books, websites, magazines and a research poster. Expertise in the field were also consulted. Accurate answers were essential. Henry acknowledged that the students responding to the survey might not have given accurate answers: It…really wasn't any way to actually see if they were precise. Well, basically you have to take the word of the person. Unfortunately…its kind of a social thing, you know, if it affects their lifestyle. So, there isn't really any way to have it accurate, and it depends on a person.	Henry was able to meet the AS for Grade 11. He thus exceeded the standard for Grade 10 students.
	Selection of "a type of display that communicates the data effectively" (DoE, 2003b, p. 21) – for Grade 11	Henry combined all the results and plans, and used a poster to summarise and display all these to communicate her science information in mathematical and pictorial forms as part of the Expo exhibition. Henry also had a report to provide a more detailed account of his project for the specific audience.	

Table 4.5a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
3. Analysing, synthesising, evaluating data and communicating findings.	Compare data and construct meaning to explain findings (DoE, 2003b) – for Grade 11	Henry's Expo report showed that, instead of comparing his data, he simply grouped it: "The allergies were divided into four main groups, the allergies themselves and the causes of the allergies, namely, 'Asthma', 'Rhinitis', 'Skin/Eczema', and 'Others' ([e.g.,] Bee sting)". In order to construct meaning out of his data he constructed a database in Microsoft Access prior to coming up with graphs. The graphs became instrumental in his proficiency in explaining the findings in accordance with the trends. For instance, he found high incidences of asthma from the students at Protea High School who reside in Emerlo. Henry explained his finding. Firstly, he stated that there are industrial plants surrounding Emerlo, which emit hazardous fumes. Then he continued: "…one of the primary causes for asthma are fumes given off by factories. This, basically, substantiates the results that were found in the study as they definitely correspond".	Henry was able to meet the AS for Grade 11. He thus exceeded the standard for Grade 10 students.
	Draw conclusions and recognise inconsistencies in the data (DoE, 2003b) – for Grade 11	Henry had several presumptions about allergies. One of them was that allergies are related to stress. His report showed that he found that 62% of the students investigated claimed that stress had negative impact on their allergies. Henry concluded, based on prior knowledge, that stress can affect allergies because the former can induce imbalance in one's immune system – a situation that can result in the latter escalating. Similar to Felicia, Henry did not show any inconsistencies discovered in the data probably because he also had no specific technique to be used to check the accuracy of his data (see 2.).	

Table 4.5a continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
3. Analysing, synthesising, evaluating data and communicating findings.	Assess the value of the experimental process and communicate findings (DoE, 2003) – for Grade 11	Likewise, Henry's investigation was part of the projects that were submitted for Expos. He was able to describe the value of his survey and findings. For instance, he believed that his study could help people make informed decisions regarding factors related to allergies, such as a place of residence and pets they intend to own (his examples). According to him: "[The project will also] create awareness of a variety of allergens and how to avoid, control and possibly prevent illness".	Henry was able to meet the AS for Grade 11. He thus exceeded the standard for Grade 10 students.

Table 4.5b

Henry's developed Life Sciences knowledge as stipulated by the DoE (2003b) – Learning Outcome 2: Construction and Application of Life Sciences Knowledge (for Grade 10)

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
1. Accessing knowledge	Use of "various methods and sources to access information" (DoE, 2003b, p. 25) – for Grade 11	Henry thought a phenomenon he investigated "should be addressed holistically". Hence, the investigation encompassed an aggregate of Life Sciences knowledge on, for example, allergies and human nutrition and effects of lifestyle and local pollutants on human health (e.g., allergies), which he was able to access. For instance, he was able to address the background knowledge by gathering information essential for acquisition of new scientific knowledge specifically on cause, correlations and effects of allergies in high school students. The sources of the knowledge included expertise in the field in two Professors – one from a local university's Lung Institute and one from a local children's hospital. In addition to discussions he had on allergies with one of the expertise, he obtained assistance in the form of resources, which included relevant pamphlets, books, websites, magazines and a research poster.	Henry was able to meet the AS for Grade 11. He thus exceeded the standard for Grade 10 students.

Table 4.5b continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
2. Interpreting and making meaning of knowledge in Life Sciences	Identification, description and explanation of “concepts, principles, laws, theories and models by illustrating relationships” (DoE, 2003b, p. 25) – for Grade 11	Evidence from the data showed that Henry’s understanding of the newly acquired knowledge from the sources in 1., enabled him develop the key scientific/health concepts that are related to the health conditions (e.g., Asthma, eczema, rhinitis, etc.), which included causes and symptoms. For example, analysis of his Expo report showed that the new knowledge acquired included categorising and explaining five allergies and “what causes them and their symptoms”. The project itself became a means of tracing the sources (e.g., hay fever [his assumption, which was confirmed]), and incidences of allergies (e.g., in 3 high schools) and their impact on people of his own age.	Henry was able to meet the AS for Grade 11. He thus exceeded the standard for Grade 10 students.
	Evaluation of “concepts, principles, laws, theories and models” (DoE, 2003b, p. 25) – for Grade 11	It should be noted that information from 2001-2007 scholarly publications – Current Allergy & Clinical Immunology Magazine – and other sources (see 1.) enabled Henry to evaluate different ideas on the causes of allergies in high school students. Hence, the implication is that, his Expo report’s “Theory” section provided the synthesised material resulting from cross–referenced material containing the different ideas.	

Table 4.5b continued

Assessment Standards (AS)	Indicators of AS achievement	Evidence related to the achieved AS from the triangulated data	Comments
3. Showing an understanding of the application of Life Sciences Knowledge in everyday life.	Evaluation and presentation “of an application of Life Sciences knowledge” (DoE, 2003b, p. 27) – for Grade 12	Henry’s Expo report showed that he had proficiency in illustrating the applicability of Life Sciences (e.g., health sciences) to everyday life. A section “Application” in his Expo report showed that he sought to equip students of his own age and/or other people with “more knowledge about allergies” common to them and how to solve allergy–related problems in their daily life. The report revealed the following examples: ▪ **Learning about allergies**: “We need to know the main causes for allergies in order for us to know what we should or should not have”. ▪ **Planning a place of residence**: Because the location became an important issue concerning allergies such as asthma and rhinitis, allergies should be considered when thinking of a location to live. In other words those prone to hay fever should not live near flowers or trees or near industrial areas which emit fumes and gases. ▪ **Awareness**: “people should be aware of how smoking can affect children”.	Henry was able to meet the AS for Grade 12. He thus exceeded the standard for Grade 10 students.

CHAPTER 5

DISCUSSION

Introduction

In this chapter, I discuss the results presented in Chapter 4. I restate the rationale of the study in order to place it in context. An overview of the study's research design is presented next, together with its limitations. The chapter continues with discussions of the answers to the study's research questions. These are followed by a discussion of the significance of the study, recommendations for further research, and concluding comments.

Many efforts in science education focus on making students' attainment of science process skills a major goal of such education (Chapter 2, p. 56). These efforts are founded on the notion that process skills form the basis for students to learn problem–solving skills, think critically, and make decisions (e.g., DoE, 2003b). Furthermore, students may also develop scientific concepts with understanding and insight (Rambuda, 2002). Indeed, in the South African's Life Sciences curriculum, it is stated that ordinary students must be able to use and develop process skills within the context of an expanding framework of scientific knowledge (DoE, 2003b). Expos provide such a context. This study, therefore, specifically focuses on these educational outcomes (that is, process skills and Life Sciences knowledge) and the opportunities ESKOM Expos provide for students to develop such educational outcomes.

The development and refinement of students' science process skills, however, remains an educational challenge (Arena, 1996), even today (Bentley, Ebert, & Ebert, 2007). The literature (Chapter 1, pp. 14-16) shows that there are several reasons being put forward both at classroom level and beyond the classroom regarding the challenges. In South Africa, in particular, the challenges related to the development of science process skills can be traced back to the nature of the curriculum itself and to classroom practices (de Jager & Ferreira, 2003). Such challenges are expected, as South African education policy (i.e., outcomes–based education) has been questioned (e.g., Chapter 1, p. 12). The challenges have led to rhetorical debates about students' proficiency in achieving the educational outcomes (science process skills), even in developed countries (e.g., Millar, 1989, 1991, 1997; Millar & Driver, 1987; Wellington, 1989). Despite these debates, many researchers and advocates of extra–curricular activities (among them, Science Fairs and Expos) have shown that students are able to develop the educational outcomes beyond science classrooms (Bencze, Bowen, & Arsenault, 2008; Bunderson & Anderson, 1996; Coskie & Davies, 2007; Czerniak, 1996; Galen, 1993; Schneider & Lumpe, 1996; Woolnough, 1994).

Hence, the purpose of this study was twofold. Ordinary students studying Life Sciences are expected to develop scientific skills, namely science process skills, including inquiry, problem solving and critical thinking skills, and to "use them to interpret and use Life Sciences concepts in explaining phenomena" (DoE, 2003b, p. 9). Utilising able students who enjoyed science and were chosen by their mentors from their science classes, the purpose of this study was to analyse the details of their performance regarding process skills, and their understanding of Life Sciences concepts. Secondly, Expos provide a context in which process skills can be *best* developed (Chapter 1, p. 2). The purpose of this study was therefore to provide further insight into the students' experiences related to the Expos. This implies that the students' own biographies became essential components of the study.

The following were the main research question and the sub–research questions of the study, which I sought to answer within the context of Expos in the Western Cape, South Africa (Chapter 1, p. 6):

How do ESKOM Expos for Young Scientists facilitate the Life Sciences' goal of students' development of scientific skills within the context of an expanding framework of knowledge?

The sub–research questions are as follows:

1. What factors shaped school students' participation in the ESKOM Expo competitions for Young Scientists?
2. How did Expo projects facilitate the students' development of scientific skills and Life Sciences knowledge?
3. What articulation occured between the Expos, the science curriculum and science classroom practices in support of the students' development of scientific skills

and Life Sciences knowledge?

In order to provide answers to the questions, I used a qualitative research approach. This approach was suitable in that it enables one to collect data and analyse personal *experiences* of participants in a quest to *understand*, *describe* and *explain* the phenomenon under investigation (Chapter 3, p. 63). In this case, the students' experiences encompassed factors which shaped their participation in the 2007 Expos. As narratives or life histories are components of case study methods (Babbie & Mouton, 2001), I utilised them to elicit such experiences from the participants.

The *research strategy* employed was that of the *multiple case study*. This design is appropriate to the type of investigation in which analyses and interpretation of uniqueness of participants through accessible accounts are made possible through the use of *wide sources of information* that are *rich in context* (Chapter 3, p. 66). The *data sources* included personal interviews and pertinent documents. The interviews were used to explore and document the Expo students' experiences at home and at school as they related to the Expos, and their future aspirations as they were realised through the Expos. The same approach was used with the students' mentors to substantiate and/or add to their reports on their own science learning experiences in their respective schools (Chapter 3, pp. 79-80). The student interviews were also used to investigate the students' developed scientific skills and Life Sciences knowledge, some of which were presented in details in their respective Expo reports. The documents encompassed the students' project reports together with questionnaire data, which was the first to be collected, to investigate the participants' developed skills and knowledge, as well as their experiences related to the Expos (Chapter 3, p. 77). The data sources were used for triangulation purposes.

The qualitative research paradigm also acknowledges both the researcher as the prime instrument of investigation (Neuman, 2006), and suitable selection of the informants (Silverman, 2010). I had criteria for selecting the cases (Chapter 3, p. 70). The location of the competitions and ease of access to the Expo participants' exhibitions became instrumental in selecting the cases from a pool of Expo participants, especially those who could provide me with relevant information (Chapter 3, p. 68). The cases were thus *purposefully selected*, and comprised senior school students (in Grades 10-12) from three schools in the Western Cape.

There are measures that may be utilised to maximise the *trustworthiness of the results* in qualitative research (Chapter 3, pp. 82-83). These measures were used. Indeed, the pilot studies conducted offered insights in different ways (Chapter 3, p. 73). One of the ways was the need for triangulating data during the main study. *The triangulation technique* in which the information in students' research projects was supplemented and complemented by data from the interviews and questionnaire, as well as video–recording and tape recording, added credibility to the information in the Expo project reports. However, a single study cannot provide conclusive results, considering that each study may have several constraints which may have an impact on its results. Future researchers in the field of science education might consider the constraints in the current research design, which included the following aspects:

- *Access*: The study used qualitative data to address the research questions regarding the students' Expo related experiences and the associated skills and knowledge. The collection of data had limitations with regard to the nature of the accessible participants and of their projects, the number of the participants, the accessible categories under Life Sciences, and, in some cases, the inconsistency in the locations of data collection. For instance, data could be collected only from English–speaking students. Only one out of the five participants was male. Data was collected from only two types of investigation – the dominant 'pattern seeking', together with 'fair testing' and 'fair testing and comparing'. Only a few Expo students out of a possible 40 students volunteered, and their projects were only in the health care and medical sciences categories. Those volunteering students could only be accessed for interviews at the Expos, not at their schools, and vice versa. The implication is that access constrained the following key issues in the study: The variety of students' investigations, gender and mother tongue.
- *Life Sciences*: The results of the study were based on a few selected cases of students from a few schools (Chapter 3, p. 69), whose projects were only in Life Sciences categories. The implication is that, since I did not design a large–scaled study, the results need to be interpreted with caution when answering and discussing the research questions in the next section.

Answers to the research questions

In this section, I present answers to the research questions (pp. 217-218). Firstly, identified factors that shaped Expo students' participation in the 2007 Expos are discussed in relation to the research and literature. Secondly, I discuss the students' development of science process skills, scientific inquiry, problem solving and critical thinking skills and Life Sciences knowledge. Lastly, I discuss possible tension or harmonious interplay between Expos, the science curriculum, and/or science classroom practices. The discussions of the answers to each research question will be completed with an overall conclusion and/or recommendation.

Research Question 1: What factors shaped school students' participation in the ESKOM Expo competitions for Young Scientists?

The consensus of opinion among advocates of extra–curricular activities (i.e., Expos/Science Fairs) is that, while participation in such activities can be a valuable learning experience for students, only limited research exists on factors which influence participation in them (Czerniak & Lumpe, 1996). One of the major goals of this study was therefore to discover factors which shaped students' participation in the South African science Expos – the extra–curricular activities which, according to Rochford (2007), form the basis for students' application of educational outcomes (scientific skills and knowledge) stipulated in the South African curricula. The answers to the first research question are subdivided into the themes presented in Chapter 4 (e.g., Expo students' reasons for participating in the Expos [p. 91]).

Students' reasons for participating in the Expos

The reasons reported by Expo students for their participation in the 2007 Expos were twofold. Firstly, Expos were part of their schools' ethos and were incorporated in science programmes that provided active inquiry at the schools (Chapter 4, pp. 98, 101, 108, 112, 117, 122). This finding is in line with other research in which students' participation in extra–curricular science activities was a class requirement at schools (Abernathy & Vineyard, 2001; Bunderson & Anderson, 1996; Czerniak & Lumpe, 1996; Gifford & Wiygul, 1992; Smoak & Williamson, n.d.). Such classes aimed to develop students' research skills while providing active inquiry opportunities (Balas, 1998).

Secondly, the students participated for personal reasons. For instance, Alina and Henry participated to improve their resumés (Chapter 4, pp. 92, 117). Henry also thought it was a "nice motivation" to participate (Chapter 4, p. 117). These findings are similar to those of Rochford (2007) in which students' participation in the 2005 Expo was based on, for example, building a career and the personal motivation to be successful. Furthermore, researchers such as Bencze and Bowen (2009b) argue that students may be motivated to participate by learning opportunities that might “lead to a more informed perspective” (p. 103). For Alina, such an opportunity was based on experiencing the type of scientific questions raised by other participants (Chapter 4, p. 93).

The following personal reasons were also found in the other two cases (Gertrude and Felicia):

- The opportunity to follow one’s passion for science, “invent something with great meaning to today’s society”, and obtain good class marks (Gertrude; Chapter 4, p. 112);
- The motivation to share ideas and make new friends, have a good experience, improve one’s communication skills, and gain confidence (Chapter 4, p. 108).

The findings from the two cases were akin to Stewart, Qanya, and Rochford’s (1999) findings in which meeting other people at the Expo and doing something new for the community were stated. Further similar results were found in other research in which students’ participation was based on the development of new skills (Smoak & Williamson, n.d.); these encompassed improved presentation skills (Czerniak & Lumpe, 1996) and the associated building or strengthening of self–confidence (Chapter 2, pp. 33, 36). Czerniak and Lumpe (1996) also presented factors such as improving one’s grade, enjoyment or having a good experience (supported by Abernathy & Vineyard, 2001), and meeting new people.

The findings of the current study suggest that, by encouraging students to participate in Expos, teachers might actually induce in them a sense of independence and freedom, to develop themselves by shaping their future careers through getting better grades, improving their social and communication skills, and their resumés. In general, participation in Expos appears to be a good experience for students.

While it was essential to know the students’ reasons for taking part in the Expos, it was equally important to know the origin of their ideas about investigating biological phenomena.

Origins of students' ideas for their Expo projects

The current study showed that Expo students drew their scientific ideas for their science projects from their everyday life. One student reported that her ideas were generated from *critical research* (e.g., Hormone Replacement Therapy [HRT] and breast cancer [Chapter 4, p. 109]); two others based their ideas on *random incidents in the students' families* (e.g., diabetes [Chapter 4, pp. 93, 113]); and a further idea was drawn from both the research and incidents (e.g., video games [Chapter 4, p. 101]). The only male participant in the study drew his idea from an *interaction with peers at school* (Chapter 4, p. 117). Thus, critical research, incidents at home, and interaction with peers at school formed the springboard for the students to investigate the contemporary social challenges and problems in South Africa through their school projects. The problems investigated were either illness and disease and/or medical conditions (allergies and asthma, cancer and diabetes [Chapter 4, pp. 93, 109, 113, 116]), while the social challenges were related to video games and the use of HRT (Chapter 4, p. 101, 109).

The findings of the study were congruent with other research by Tytler (1992), Tytler and Swatton (1992), and So (2003). As Tytler (1992) and Tytler and Swatton (1992) eloquently put it, the basis for students learning through research projects in school science might be random events in family life, significant hobbies of interests, or a combination of these. So's (2003) study further showed the importance of students' daily experiences in generating ideas for their projects. She also reported that the ideas of the students she studied "were generated from their previous learning" (So, 2003, p. 183).

The findings of the present study support Tytler's (1992) views that, when a student participates in extra–curricular science activities, "the associated projects are normally based on a specific desire to find out *something that had some sort of relevance in the personal life of the student*" (p. 407; emphasis added). The findings also suggest that the knowledge that students obtain through everyday experiences and/or critical research may be useful in creating the kind of student who could influence the present South African society and shape its future. The South African science curriculum "seeks to create a lifelong [student] who is...multi–skilled, *compassionate*, with...the ability to participate in society as a *critical* and active citizen" even before a student reaches Grades 10–12 (DoE, 2002, p. 8: emphases added). Indeed, the 2007 Expo competitions elicited such qualities that are typical of the kind of students envisaged in the curriculum. For instance, students who could solve the problems facing society today (p. 222) and those who are compassionate (Chapter 4, p. 117) or critical (Chapter 4, pp. 109, 161).

The origin of Expo students' interest in science

Woolnough (1994) argued that "interest and motivation rather than intellect are key ingredients in pursuing a piece of research or models to a successful conclusion" (p. 51). Likewise, interest and the motivation to investigate problems and challenges related to biological phenomena (p. 222) suggest that the 2007 Expo students were interested in science and/or biology. After all, they were able to pursue their respective investigations to a successful conclusion, and subsequently participated in the Expos. What were the aspects that aroused and maintained these students' interest in science? Adapting Hasan's (1975) ideas regarding "factors affecting science interest of secondary school students" (p. 255), Expo students' *favourite subjects* and *career inclinations* constituted aspects related to "Inner Motivation", while the presence of a *family member in science field* (e.g., medicine) denoted those related to "Outer Motivation" (p. 259). Important things the Expo students learnt in biology or science, areas of interest that shaped their investigations, biology or science as a subject at school, as well as the role of science in their lives, were other factors explored and analysed to supplement the aforementioned aspects (Chapter 4, p. 93).

In general, the findings of the study revealed that Expo students' aspects related to inner and outer motivation, including the other factors investigated, such as areas of interest, shaped their interest in science, their subsequent projects, and their participation in the Expos. For example, areas thought to be important in science/biology and/or were of great interest to the students were all related to human biology and health. These areas encompassed aspects of the human body (Chapter 4, pp. 94, 101, 114), related to diabetes, allergies, blood pressure, and cancer research. The findings are congruent with those of Christidou (2006), in his study of 583 ninth–grade Greek students from 27 different schools. His findings enabled him to suggest that the Greek science curriculum might enhance the students' interest in science by enriching it with topics related, for instance, to "Human biology, health and fitness" (p. 1194). Furthermore, virtually all the participants had medicine as their career option (Chapter 4, pp. 93, 102, 114, 118). Hasan's (1975) study on 340 eleven–grade Jordanian science students also showed that both boys and girls with high interest in science exhibited a desire to follow a career in science. The current Expo students who had family members in the science field (Alina, Felicia, Gertrude, and Henry) had their interest in science shaped by various forms of assistance offered to them when pursuing their projects (see next section). This is in line with the findings of Philpot's (2007) study, in which she studied seven cases of students who participated in a Science Olympiad in the United States. Five of the students had parents in a science field. The parents offered assistance which, she concluded, shaped the students' interest in science. Similar results about parents in the science field and their influence on their children's interest in science were also found in Woolnough (1994): "Home background, with one or both parents in science, medicine or engineering, clearly made a difference" (p. 38).

In short, Expo students' areas of interest in school science, the careers they aspired to, and the support of family members in the field of science formed the basis for the origin of their interest in science. Moreover, all the Expo students appreciated biology and/or science and acknowledged science's impact in their lives (Chapter 4, pp. 93-94, 102, 109, 114, 118). However, Felicia was uncertain about her future career (Chapter 4, p. 109). Furthermore, the favourite subjects reported by Felicia and Henry contradicted their evident interest in science (Chapter 4, pp. 109, 118). Results similar to these unexpected findings (Felicia's and Henry's) were reported by Philpot (2007). The participants she studied (p. 224) were "high achieving science students who were interested in and excited about science" (p. 9). However, her results showed that only two of the seven cases studied had science as their favourite subject.

The current study's findings suggest that career inclinations and the homes of students who participate in science competitions – especially those with members in the science field – can arouse and maintain the students' science interest. Moreover, the topics or content areas, such as *structure, control and processes in basic life systems of plants and man* (DoE, 2003b), were also among the factors that shaped their interest in science/biology (Chapter 4, p. 101, 114). Consequently, schools may include them in their enrichment programmes in Life Sciences. However, the findings (e.g., Chapter 4, p. 118) also suggest that teachers should be aware that Expo students' interest in a particular field (e.g., Health Sciences) and a related career path (e.g., medicine) may not necessarily indicate that the origin of their interest in science is purely based on Life Sciences/Physical Sciences and Mathematics.

Overview of roles played by Expo students' homes and the resources used

Family support (Neu, Baum, & Cooper, 2004) and the utilisation of facilities and resources in general may have a significant impact on the success of school students participating in extra–curricular science activities (Gifford & Wiygul, 1992). Indeed, 1996 students from the University of Ballarat, Peninsula Technikon and Cape Town Expo ranked their parents in the top two of the most influential sources of support for their projects (Stewart *et al*., 1999).

In this study, the inspiring (Chapter 4, pp. 103, 115, 117), supporting (Chapter 4, pp. 95, 103, 110, 115, 119) or encouraging (Chapter 4, p. 95) behavioural traits in the Expo students' families were influential in ensuring the success of their projects. In some instances, the family members were even regarded as role models (Chapter 4, pp. 110, 115, 118). In regard to encouragement, similar findings were reported by Subotnik, Miserandino, and Olszewski–Kubilius (1996) and Neu *et al*. (2004). Encouragement formed the basis of the success of the students who were studied, especially when they were overwhelmed by their school projects.

Some interesting commonalities and differences were also discerned in the Expo cases in relation to the home–based support and advice given to the students, as well as the resources utilised by them. Firstly, family members were not only the students' personal mentors (e.g., Chapter 4, p. 95) but also played different roles. There were instances where they were instrumental in the students' access to sophisticated equipment owned by family friends (Chapter 4, pp. 103, 115). Specifically, the mothers provided transport services (Chapter 4, pp. 103, 110, 119), for example, to libraries (Chapter 4, pp. 111, 119), while the fathers and other family members (i.e., siblings) gave technical advice (Chapter 4, pp. 110, 119) related to selecting a project or brainstorming project possibilities. The conclusion is that the Expo students had access to family members who became their personal mentors. There were as well students who had access to expertise in their respective areas of study (Chapter 4, pp. 103, 115, 119). All these human resources consulted were acknowledged.

Similar reports are found in the literature regarding the different forms of parental and/or family support that were influential in the students' success in extra–curricular science activities. For instance, the support provided to winners in such activities included the supply of equipment and materials (Neu *et al*., 2004; Tytler, 1992) through the use of a parent's or friend's business (Gifford & Wiygul, 1992).

Furthermore, the support also entailed provision of transport (Czerniak & Lumpe, 1996) to laboratories (Neu *et al*., 2004), libraries (Tytler, 1992), and competitions (Subotnik *et al*., 1996). Family members themselves became personal mentors and provided technical advice (Czerniak & Lumpe, 1996; Tytler, 1992). Rodia (2004) adds that mentors could actually be useful in selecting a project and brainstorming project possibilities. Use of human resources in the form of personal mentors of participants was also found in the study of Neu, *et al*. (2004) and that of Pyle (1996). In So (2003), a few students drew on human resources for relevant information.

A commonality discerned in relation to information, supplementary to the abovementioned human resources, was access to the Internet, and its use (Chapter 4, pp. 95, 103, 111, 115, 119) for opinions and information relating to the Expo students' respective areas of interest. This is consistent with Lorenzen's (2001) assertion that high–school students today are Web–oriented. It also confirms that schools today emphasise the use of Internet by students (e.g., Chapter 4, pp. 97, 105). Moreover, different secondary sources of information pertinent to the students' investigations were used by them. These included encyclopaedias or books (for background information in the five projects), as well as magazines, medical journals and pamphlets from doctors/doctors' waiting rooms, to supplement the background information (Expo reports: Gertrude and Henry).

In Bencze and Bowen (2009a), Science Fair students reported that they had access to the Internet which they used for their project work. Such work might include search for ideas (Thompson, 2006) or secondary sources of information pertinent to the students' investigations (So, 2003). Furthermore, similar to the current study's findings, the use of books dominated in So's (2003) study. The Hong Kong primary students also used magazines, commercial products (for example, information about the function of vacuum cleaners), but not secondary sources such as encyclopaedias, journals, and pamphlets. Moreover, unlike Expo students, *a few* Hong Kong students obtained information from human resources (parents and their schools' workmen [So's (2003) example]). So (2003) also reported on the students' ability to acknowledge their sources: "Only half of the 24 reports mentioned the children's sources of information" (p. 185).

The findings of this study suggest that the success of high–school students in Expos is based on support from their families and other human resources (e.g., expertise in the relevant field of study). As the students used sophisticated approaches to their investigations (Expo reports: Felicia and Gertrude), they tended to use Internet and more references (secondary sources of information, such as encyclopaedias, magazines, and journals). Such approaches to their investigations also included the use of other important resources.

Expo students used sophisticated and authentic equipment and materials, and/or sophisticated programmes. These included:

- A Glucometer to test the blood glucose levels in various subjects and compare them (Alina [Chapter 4, p. 136]).
- Graph Pad InStat and Graph Pad Prism to compute statistical analyses (Felicia [Chapter 4, p. 187]).
- Blood pressure monitor used to measure the blood pressure (Elizabeth [Chapter 4, p. 103]).
- Microsoft Access – a database programme used to record information from the surveys conducted (Henry [Chapter 4, pp. 201-202]).
- A Topcon Fundus camera (Gertrude [Chapter 4, p. 115]), together with a laptop, a ready–made eye model (Figure 4.1, p. 167), and "Paint" programme (Chapter 4, p. 169).

Use of high–tech equipment in Science Fairs by school students has also been reported by Rodia (2004). Manipulation of such equipment, materials, and programmes shows the importance of the introduction or application of what Fletcher (2007) calls "21st–Century skills" in schools. Such skills might entail students using "technology to gather data, analyze and synthesize the data, and make suggestions based on facts" (Fletcher, 2007, p. 27). In this way, students are trained to approach science in a problem–based way (i.e., using school projects).

The overall findings of the current study suggest that the home environment provided Expo students with a place where their interests, concerns, and ideas could be developed. Such environment could also provide direct assistance from the family through, for instance, the provision of inspiration and encouragement, as well as resources and facilities. The students also become more aware of the importance of using and acknowledging expertise in fields pertinent to their investigations – a phenomenon that was emphasised by their mentors (e.g., Chapter 4, p. 123).

Overview of Expo students' learning environment related to the Expos: Insights from the 2007 Expo students and their mentors

Teachers' guidance of students, the availability of teaching and learning resources, as well as physical facilities and the ethos of their schools, are some of the factors that determine students' success in learning both in schools and beyond the classroom (Salfi & Saeed, 2007). Salfi and Saeed (2007) suggest that for students to successfully develop their skills within the context of an expanding framework of knowledge (i.e., Expos) in South Africa, these factors have to exist. The students' learning process should encompass, for instance, "a *learner–centred* and *activity–based approach* to education" (emphases added) which emphasises the development of process skills (Outcomes–Based Education) (see DoE, 2003b, p. 2).

However, a *teacher–centred approach* to solving problems was common in the classrooms in both Western Cape High School and St. Peter's Grammar School (Chapter 4, pp. 96-97, 105). As expected, such practise is common and exists, especially in middle school, even in developed countries such as the United States (Trumbull, Scarano, & Bonney, 2006). In South Africa, Villanueva and Webb (2008) argued that, despite the introduction of the new science curriculum, "the most common approaches still usually consist of traditional experiments which simply verify a scientific principle or concept" (p. 4). Teachers at Western Cape High School and St. Peter's Grammar School used an approach that Berry, Mulhall, Gunstone, and Loughran (1999) referred to as "closed investigations". This approach was used in tandem with the scientific method (Chapter 4, pp. 96, 105). Watson and James (2004) assert that the scientific method could be a functional tool for introducing students to the problem–solving nature of science. The scientific method has become a structure of experimental set–ups for students at both the schools' laboratories. In Mr. Paul's opinion, the skills the Western Cape High School students learnt from conducting practical work using closed investigations and the associated scientific method prepared them for the more advanced scientific investigations related to Expos (Chapter 4, p. 97). Indeed, Watson and James (2004) argue that the scientific method is used as a structure of students' laboratory reports. In St. Peter's Grammar School, research work was also assigned to the students when they conducted practical work using closed investigations and the associated scientific method. Ms. Nicola reasoned that the research work provided "a way of thinking" for the students (Chapter 4, p. 105). Watson and James (2004) further argue that the scientific method could be a useful tool in developing students' critical thinking skills.

The teacher–centred approach employed at Western Cape High School and St. Peter's Grammar School may have been limited, especially in regard to the students' development of high–order process skills. Indeed, Arena (1996) argued that such skills are best developed through an open–inquiry style.

The open–inquiry style approach may be part of student–centred programmes that include school projects (Chapter 2, p. 53). In Protea High School, such programmes were a norm (Chapter 4, p. 117). Expo students from the school reported that tutorials, utilisation of smart boards for PowerPoint presentations, and books were part of the teaching and learning process at the school (Chapter 4, p. 120). However, Mr. Daniel emphasised that, to develop the students' skills and knowledge, the fundamental premise of instruction at the school was "high experimentation and high expectations [from teachers]" (Chapter 4, p. 121). The instruction included preparation of students to actively internalise knowledge through their past experiences and apply knowledge learnt at school to the real world – "a kind of developmental…constructivist theory type of approach" (his words). This distinctive approach produced "incredibly good" results at the school (Chapter 4, p. 121). Balas (1998) argued that participation in Science Fairs or Expos also contributes to learning within the constructivist framework. Balas's (1998) assertion suggests that the good results of the performance of Protea High School students at the 2008 Expo (Chapter 4, p. 122) were the result of learning within the constructivist framework, both at school and in the Expos.

The findings of the present study suggest that the scientific method remains the main functional tool for introducing students to the problem–solving nature of science. Moreover, scientific investigations, by using the scientific method, have an element of structure (i.e., are teacher directed) (Watson & James, 2004), which is encouraged (Dickinson, 2006). Indeed, St. Peter's Grammar School produced their best results at the Expos using a structured approach to solving problems (Chapter 4, pp. 105-106). However, given Bencze and Bowen's (2009b), Chiappetta and Adams' (2004), and Craven and Hogan's (2008) views on the scientific method, and certain Expo students' flawed perception of this method (Chapter 4, pp. 127, 145), it is also important that teachers broaden the students' understanding of this method. The teachers could start by introducing the associated process skills embedded in each of the scientific method's classical steps, and state the importance of those skills.

Teachers' guidance of students is thus crucial. For Balas (1998), such guidance might include preparing students for Science Fairs/Expos by engaging them in the process of seeking and gaining knowledge. All three schools had some form of support in the different resources essential for their students to obtain the knowledge they needed for their projects. This may also explain why in the study of Stewart *et al*. (1999), students ranked their teachers' support and encouragement highly with respect to their projects. Statter and Tamir's (1998, p. 224) national survey, in which biological research projects were examined in Israeli high schools, also revealed that "supportive" schools offered relevant instructions and resources. Thus, the findings of the current study contradict one of Woolnough's (1994, p. 50) assertions, based on results from Tytler's study, namely that "the amount of help needed and received [by the participating students] from the school or teacher was *very small*" (emphasis added).

Furthermore, the three participating schools had organisational structures in place, for example, grades that were selected to participate in Expos (Grades 10-11), students' and mentors' distinctive expectations and roles, and school–based Expos (e.g., Chapter 4, p. 98). The schools also employed strategies to improve the success of their students' projects at the Expos. For instance, the students were provided with the standard Expo judging sheet to enable them meet the Expo requirements (Chapter 4, pp. 106, 122). Moreover, the participating grades were challenged to meet the schools' ethos in relation to the Expos (Chapter 4, pp. 98, 106, 121). The schools also prioritised certain Expo expectations (50% in Part A of the Expo's scoring sheet is allocated for a project's level of investigation and creativity [Chapter 4, p. 124], and 30% of Part B of the scoring sheet is allocated for an Expo exhibition/project's display [Chapter 4, p. 100]), and provided their students with incentives (Chapter 4, pp. 99, 107, 124).

This study's findings were similar or slightly different to those found in Statter and Tamir's (1998) study. For instance, unlike in the current participating schools, their study showed that "in most of the schools the research project is optional for students" (p. 224). Furthermore, most of the research projects are written in later grades, namely Grades 11 and 12. However, similar to the participation requirements in the Western Cape High School and St. Peter's Grammar School, Israeli schools require an individual or group research project. Moreover, Israeli participants are provided with relevant instructions, and also have access to libraries with relatively rich collections of the materials they need.

The overall findings of the current study suggest that success in students' science learning at the Expos is a product of a school environment that challenges students, while the students are also provided with enough support in terms of resources and facilities. Schools with such an environment also had good organisational structures in place, and strategies that were strictly followed by teachers and students as a team. The findings further suggest that the scientific method was the key component of the teaching and learning process at the three schools. However, even in the school in which the method was employed together with the student–centred approaches (p. 229), the students did not have an extensive understanding of the method. For instance, they did not recognise that, although the scientific method is a model of the basic procedure involved in science projects (Bochinski, 1991), it involves various steps, definitions and processes (Watson & James, 2004).

Conclusion

ESKOM Expos strive for investigative projects that are inventive and innovative (Chapter 1, p. 17). Hence, as expected, the current Expo students' projects were not only based in several contexts but also presented novel and creative ways of solving some of the contemporary social challenges and problems in South Africa. The contexts were rooted in these students' experiences at home or school, previous learning/critical research, as well as in the media. The contexts, by virtue of being familiar and meaningful to the students, proved to be pivotal in the development of their process skills, along with other pertinent cognitive abilities. The results of the study also showed the role played by the students' inquisitive natures, interest in science learning, their families and the associated resources and facilities at home, and the nature of their school environment. The results, in fact, support Balas's (1998) argument that collaborative interaction between students, teachers, mentors, and parents enhance students' experiences related to the development of educational outcomes (i.e., skills and knowledge). Hence, it can be concluded that, apart from the concepts of personal relevance and interest (Arena, 1996) and curiosity (Parker & Rochford, 1995), the following additional factors shaped the students' participation and experiences in the 2007 Expos:

- The link between their projects and their families and home life.
- Collaborative interactions with peers and teachers at school.
- Effective science teaching in tandem with extra–curricular science activities.

Recommendation

Instructing and guiding students in research projects can be quite challenging for science teachers (Woolnough, 1994). However, the South African annual ESKOM Expos for Young Scientists play a significant role in the teaching and learning process providing contexts enriched with relevance to the students' interests and concerns. Expos should thus be and remain part of a school's ethos. However, schools should be aware that facilities related to Expos, financial resources, and extensive professional assistance are essential for highly successful projects (Gifford & Wiygul, 1992). Indeed, the arguments of Alant (2006) and Ramsuran (2009) related to Expos showed that the aforementioned aspects (i.e., requisite facilities) might be the primary challenges associated with Expos that make them an exclusive institution in South Africa.

Research Question 2: How did the students' Expo projects facilitate the development of scientific skills and Life Sciences knowledge?

The second research question may be considered as containing three sub–questions. Firstly, it asks about Expo students' proficiency in developing the scientific skills essential for carrying out a particular scientific investigation and explaining biological phenomena. Secondly, it asks about the extent to which the Expo students' pursuit of interests and concerns enabled them to access, interpret, construct and use Life Sciences concepts to explain biological phenomena, and their proficiency in the application of the Life Sciences knowledge. Thirdly, it asks about the Expo students' perceptions of scientific investigations as they reflected on their respective Expo experiences. The discussions of the answers to these questions will be focused on students' proficiency in developing Life Sciences knowledge and process skills in the Expo context.

Students need many opportunities to develop science processes within a variety of investigations (Germann & Aram, 1996). So (2003) suggests that, starting at an early stage (i.e., primary school), students should be granted an opportunity to work from their initial ideas to develop their scientific understanding through investigation projects. They should make "links between ideas and explanations, and between the experience of phenomena and events…by doing systematic investigations" (So, 2003, p. 198). With respect to these systematic investigations, the implication is that the students will have an opportunity to engage in active, meaningful and high–level learning – the attributes of inquiry learning (Wilke & Straits, 2005). As Colley (2006) eloquently puts it, quoting the National Research Council in the United States in the context of scientific inquiry, the students would also be provided with opportunities to

> make observations; pose questions; examine books and other sources of information to see what is already known; plan investigations; review what is already known in the light of experimental evidence; use tools to gather, analyse and interpret data; propose answers, explanations and predictions; and communicate the results. (p. 26)

Colley goes further to argue that through inquiry, students could also be challenged to show their proficiency in the identification of assumptions, use of critical thinking and logical thinking, and consideration of alternative explanations.

The findings of this study revealed that the students' scientific skills and Life Sciences knowledge had been developed to a substantial degree, especially in Expo reports. However, the triangulation technique used (Chapter 3, p. 81) revealed instances of inconsistency in the development of the students' skills, as was evident from the interviews and questionnaire data (Chapter 5, pp. 242, 244). Additional insights were also elicited from the triangulated data, for example, the challenges encountered by the students regarding their investigations. These challenges contributed to shaping their perceptions of scientific investigations. In general, the study strengthened the view that scientific skills can best be developed within the context of an expanding framework of knowledge (DoE, 2003b).

Expo participants' process skills

Expo participation provided an opportunity for the current Expo students to practice and develop their process skills and Life Sciences knowledge by connecting content learnt at school to their everyday experiences (p. 222). However, did the participation also foster their understanding of the skills? The triangulated results revealed that Expo students were involved in scientific experimentation and/or surveys, observations, interpretation, critical thinking and/or reasoning (e.g., Chapter 4, pp. 128, 134, 138, 164, 187, 109). Their projects challenged their proficiency in observing and comparing, in noting patterns and ordering and sequencing events, as well as interpreting science information, as they collected data, analysed it, compared results and came up with the underlying reasons, as the basis for the acquisition and development of their skills.

As referred to earlier (p. 232), the discussions of answers to the second research question will be focused on students' proficiency in developing process skills.

Observing and comparing. These skills together elicit an ability to obtain information about the students' environment (i.e., events or organisms) through the use of the senses (Chiappetta, 1997; Colvill & Pattie, 2002; Rambuda & Fraser, 2004). Moreover, students' proficiency in such skills can be recognised in their ability to note similarities and differences, describe them in general terms, or describe them numerically (DoE, 2002). In surveys, students are expected to show proficiency in describing patterns and ordering and sequencing events (Devereux, 2000). It should be noted that a *relevant* observation can be explained in terms of the conventional view of science education, that is, all observation is theory–dependent: "What we see is dependent to some extent on the theories which we hold" (Millar & Driver, 1987, p. 42).

The findings of this study showed that Expo students' observations, which provided the basis for their investigations, were the result of their experiences at home and/or at school (p. 222). This is congruent with So's (2003) findings with Hong Kong primary students' investigations.

After conducting their systematic investigations, Expo students were able not only to describe what they had noticed about the investigated phenomena but could also go beyond this. For instance, those who conducted experiments/tests (e.g., Chapter 4, p. 144) were able to note similarities and differences in the phenomena investigated. In preliminary and explorative studies by Molefe (2003, 2007), the same skills (observing and comparing) were successfully acquired and/or developed by school students. The successful development of these skills was also found in Expo students who conducted surveys, although the abilities of the students concerned were now related to describing patterns and ordering and sequencing events. However, whether the students conducted surveys or tests during their investigations, their observations were challenged because of the techniques they used (Chapter 4, pp. 139, 157, 175, 194, 211). For instance, they had to calculate averages (Chapter 4, pp. 139, 157) or repeat and check measurements and select suitable measuring techniques to minimise inaccuracy during quantitative observations (Chapter 4, p. 165). The findings of this study, particularly those in which Expo students conducted tests (Alina and Elizabeth), support the results of the preliminary study by Molefe (2008) in which one Expo student, who participated in the 2006 Expo, was able to develop observing and comparing skills. The student's success in developing these skills was rooted in the background information she had researched, her ability to read the instruments she used, to calculate averages, and to accurately observe details of the phenomenon she studied (Molefe, 2008).

The findings regarding the Expo students' proficiency in developing observing and comparing skills support Tomkins and Tunnicliffe's (2001, p. 810) view that "everyday *knowledge* and *experiences* are employed as illustrative of what is seen" (emphases added). The findings suggest that the Expos became a springboard for tapping into such everyday knowledge and experiences (Chapter 2, p. 29). Moreover, because quantitative observations also involve technical skills, such as measuring techniques (Chapter 2, p. 29), students have to address technical challenges before they can make proper observations and/or comparisons (e.g., Chapter 4, p. 139), or deduce data patterns (Chapter 4, p. 165).

Measuring. This skill is associated with students' proficiency in utilising instruments accurately, reading scales and using intermediate points between divisions on scales, choosing appropriate instruments or appropriate scales on instruments, and knowing when it is important to record data (DoE, 2002). Also included are the students' ability to recognise the need to repeat and check measurements, variability and reliability of measurement and arbitrary nature of units (Devereux, 2000). Previous research has shown that students perform poorly in this skill, even in developed countries. For instance, in the United States, students in senior grades (Grade 12) performed poorly in measurement compared to other nations in one TIMSS (Third International Mathematics and Science Study) study (Sterling, 1999).

In this study, the students were able to use sophisticated equipment (p. 227) to measure variables using appropriate units (e.g., Chapter 4, p. 147). One student (Chapter 4, p. 170) even developed formulae and procedures for determining measures to solve problems. The need to compute averages (Chapter 4, p. 139, 157) or repeat and check and select suitable techniques for measuring (Chapter 4, p. 165) was also evident. Nevertheless, research shows that students are prone to several misconceptions regarding measuring (Sterling, 1999). Contrary to those mentioned by Sterling (e.g., use of appropriate unit of measurement and how to correctly abbreviate it), Expo students' misconceptions were related to *accuracy* and *precision*. These two concepts were either perceived as controlling variables or associated with obtaining reliable data (Chapter 4, pp. 130, 147, 201). The problem of misconceptions about measuring were more distinct in certain investigations in which Expo students conducted surveys. For instance, in one case the student's descriptions of accuracy and precision were irrelevant (Chapter 4, p. 183), while in another case age and stress were considered as variables measured (Chapter 4, p. 201).

Thus, although Expo students were able to quantify their observations and to ensure that the observations were precise, especially in fair testing, they did not understand the concepts of accuracy and precision. This may explain why Henderson (1973) argued that remedial work in measurement, quantifying observations and establishing precision are a necessity in independent research projects for school students. Expo students' *understanding* of suitable measuring techniques and related concepts are therefore important. Indeed, in a survey that incorporated quantitative observations (Chapter 4, p. 165), the student's understanding of accuracy and precision was rooted in understanding suitable measuring techniques to establish the trustworthiness of her data.

Recording and communicating science information. Data representation may encompass both the common ways of recording information and of communicating science information (So, 2003). Hence, discussions of the answers regarding the two process skills are provided simultaneously.

Recording information involves a student collecting information in an organised fashion about objects and events that illustrate a specific situation (Horton & Hutchinson, 1997). The student may record in a prescribed form (sentences, lists, tables, labelled diagram), selecting a suitable form in which to record the information when asked to do so, knowing when it is important to record, and doing so without prompting by the teacher (DoE, 2002). Competence in communicating science information involves knowing when it is important to make an extra effort to communicate one's ideas or results, and choosing an appropriate means to communicate with the specified audience (DoE, 2002). Moreover, communicating science information in the science classroom may involve students in methods, such as giving an oral report, writing a prose text, using an art form such as poetry or drama comic strip, or using graphic forms such as posters, diagrams, and pie–charts (DoE, 2002). It may also involve more conventional forms, such as tables, concept maps, word–webs, graphs, making physical, constructed models, or using enacted models. In short, communicating science information encompasses conveying ideas to a relevant audience through, *inter alia*, verbal means, written text, pictorial and mathematical forms (Colvill & Pattie, 2003).

Germann and Aram's (1996) study in the United States showed that the ability of seventh–grade students to record data may not be satisfactory: Only 61% of 364 students tested successfully recorded data. Germann and Aram (1996) concluded that the source of the unsatisfactory performance might be that the students had difficulty in using a table because of a possible lack of experience of the conventions of recording scientific data in tables. On the other hand, different findings were noted in a research study in which primary school students learnt through investigation projects (So, 2003). The students here were able to successfully use tables and other various other forms of recording and representing data, such as words, charts, graphs, pictures and photos.

At Grade 10 level, Beaumont–Walters and Soyibo (2001) used the "Specimen Test of Integrated Science Process Skills Written Performance Items" to examine five integrated process skills of 305 students in Jamaica. They discovered that in general these students performed poorly on five integrated skills, which included recording information. Nevertheless, the students performed relatively better on the recording skill than in the other four process skills evaluated. The authors reasoned that the better performance was due to the explicitly constructed items on this skill. The items provided the students with prescriptive directions on what they should measure and how to record it.

All the Grade 10 and 11 students in the present study were able to use conventional forms of recording information, in tables, various forms of graphs and to a certain extend, photographs (Chapter 4, Tables 4.1a, 4.1b–4.5a, 4.5b). Although graphs and tables are common ways of recording data (So, 2003; Beaumont–Walters & Soyibo, 2001), Expo students showed that there are additional ways of representing information, namely, appendices, spreadsheets, diagrams and cartoons.

As students may be better at working with certain forms of recording information than with others (Beaumont–Walters & Soyibo, 2001), I wanted to find out whether that was the case with Expo students. One Expo student out of the five cases studied could state the forms of recording data she was better working with, and was also able to articulate reasons for her chosen forms of recording data (Chapter 4, p. 130). There was a further unexpected finding: One of the participants thought graphs were not used because they were not applicable to her study, yet evidence showed that they were used by her (Chapter 4, pp. 167). These two findings suggest that in order to successfully develop students' proficiency in recording information, they should be constantly asked to report the forms they used to record information when representing their data in their Expo reports, and be asked to articulate their reasons for utilising them.

The student who was able to decide on the form of recording data she was better working with (Alina [Chapter 4, p. 130]) chose graphs, since she considered they were easier to use as compared to tables. This was unexpected, considering that tables not only form the basis for graphs but are also easy to construct and can show information in details. Indeed, Beaumont–Walters and Soyibo (2001) also argue that "the construction of graphs demands the ability to recognise relations between relations or formal operations in Piagetian terms of which many students are incapable" (p. 138). However, Alina presented expected results in the use of graphs themselves. *Bar graphs* were considered easier to do and therefore preferable to *pie charts* (Chapter 4, p. 130). The pie charts were considered to be not only challenging but also inaccurate, and were believed not to show variations clearly within the variables tested.

The study's findings suggest that when students learn at their own pace, using investigations which incorporate their interests and concerns, they may develop experience of the conventions of recording data in science in various forms. The students' reasons behind utilising certain forms of recording information in preference to others may be rooted in their perception of what will work best in the representation of their data, and in the perceived ease with which they can be constructed and completed. The findings also suggest that the terminology used in DoE's (2002) description of process skills (Chapter 4, p. 130) may have a negative impact on students' *understanding* of the process skills. Indeed, the current Expo students failed to understand questions related to recording information (Chapter 4, pp. 149, 184, 202) and communicating science information (Chapter 4, pp. 148, 167, 203), because of the term "forms".

Analyses of Expo project reports revealed that Expo students could also communicate science information (Tables 4.1a–4.5a, pp. 140, 158, 176, 195, 211). The students were able to communicate their ideas using conventional forms that included tables and graphs (bar charts, line graphs and pie charts). These mathematical forms (Colvill & Pattie, 2003) (colourful bar charts and tables) dominated in the current projects.

Similar findings were recorded by So (2003).

So (2003) reported that pictures and words were also common in her study. However, she stressed that use of “non–verbal representation [i.e., photos] was sometimes more effective than when they [Hong Kong–based primary students] used words only in representing the data in their reports” (p. 188). In the current study, written descriptions of the projects were common, with over half of the Expo reports including photos/pictures. The descriptions could be supplemented with cartoons and diagrams (Chapter 4, p. 147), as well as models and written information in PowerPoint format (Chapter 4, pp. 166-167). These supplementary ways of communicating were, however, not found in So’s (2003) study. This suggest that, since at high school level students (including Expo students) engage in more sophisticated projects (pp. 227), they tend not only to select and use appropriate and diverse pictorial and mathematical forms of communicating science information but also to employ sophisticated forms to supplement and/or present their written information.

As clear data representation is important in interpreting data (Riendeau, 2007), Expo students’ reasons for choosing appropriate and diverse pictorial and mathematical forms of communicating the science information used were also important. Yet again it was only Alina who could articulate why certain form/s of communicating science information were used over others. For instance, she thought her bar graphs would “grab attention” (Chapter 4, p. 131), and also help people distinguish easily the differences in the blood glucose levels of her various subjects (Chapter 4, p. 131). She also revealed that the “visual pictures” proved useful in providing a pictorial description of how she conducted her experiments (Chapter 4, p. 131). Her reasons were similar to those given by Hong Kong primary students in which graphs were “[used] to represent changes, trends and comparison”, while photos represented “both the process of investigation and its outcome” (So, 2003, p. 188).

The findings of this study show that pictorial and mathematical forms of communicating science information are common ways of representing data and information in Expos. However, as referred to earlier (p. 238), words used in the description of process skills by DoE (2002) may have a considerable impact on students’ understanding of the skills. Additional words that may challenge the students’ understanding can be found as well in the skill of sorting and classifying.

Sorting and classifying. Learning how to sort and classify things is part of our everyday life (Millar & Driver, 1987; Millar, 1988, 1989). In school science, sorting and classifying may refer to the same thing – “grouping [and organising] objects or attributes” (Platz, 2004, p. 89). Drawing on Platz’s views, the only difference between them is that, in sorting the grouping task is shown or told to students, while in classifying students have to discover the grouping themselves. Classification, used concurrently with observation, enables scientists and students to organise the world around them (Carrier & Thomas, 2008). It may involve students using a given rule to sort *items* into a table, mind map, list or other system, deciding on their own rules for classifying, or choosing a suitable system, such as a table, a dichotomous key, or a mind map (DoE, 2002).

The current Expo students showed proficiency in sorting and classifying in their project reports. The findings are similar to those noted in Huppert, Lomask, and Lazarowitz’s (2002) study in which a computer–assisted progamme, “The Growth Curve of Microorganisms”, was used to study tenth–grade Israeli students’ mastery of selected science process skills in relation to their cognitive stages, and the impact on their academic achievement. Huppert *et al*. (2002) found that the students at transitional stage in their study had a significantly higher achievement in classification skill, when compared with the control group.

Although the Expo reports of the students showed their proficiency in sorting and classifying, in which they predominantly used a tabular format, they were unable to describe *how* they went about deciding on the rules for classifying or selecting the systems they used. Only in one case (Alina) was an Expo student able to articulate the criteria on which her classifications were based. Alina knew her subject’s status in relation to diabetes (Chapter 4, p. 132), and she explicitly stated the purpose of her investigation in her Expo report. Her knowledge (that is, of the subject’s status) and the aim of her study helped her in classifying her subjects. Indeed, Millar (1988, 1989) argued that there is an inseparable link between classifying and both the basis of one’s knowledge and commitments/purposes. Although the other students had explicitly stated the purposes of their studies, they failed to *understand* the questions asked; as a result, they could not articulate the criteria that framed their classification systems. The interviews revealed that they did not understand the term *items/scientific items* (Chapter 4, pp. 149, 168, 186, 203), not the usefulness of grouping and organising objects or subjects, or the information they used.

The findings of this study suggest that DoE's (2002) biased description of sorting and classifying (it is framed on experiments/fair testing only) may hinder students' understanding of these skills, especially in a different context (i.e., in surveys/pattern seeking). Hence, more practice is needed to familiarise students with sorting and classifying, and with the associated terminology used in the science curriculum. For example, teachers may ask students to describe their decisions or their own rules for classifying or choosing a suitable system for classification, rather than merely completing classification tasks during practical sessions.

Interpreting information. This skill may provide an opportunity for students to develop their skills in using the scientific equipment needed to produce functional data which can be interpreted (Chapter 4, pp. 132-133). It may also involve a student in changing the form of information to other forms in order to reveal the meaning of the information, predicting, interpolating for missing data, perceiving and stating a relationship between two variables, or constructing a statement to describe a relationship between two variables (DoE, 2002). Hence, it may also involve "arriving at explanations, inferences, or hypotheses from data that have been graphed or placed in a table" (Chiappetta, 1997, p. 24).

The current Expo students were able to recognise the importance of tabular and graphical forms (p. 237) in relation to clear data representation. This was important. Riendeau's (2007) study showed that these forms of data representation could enable students see trends in their data, and interpolate between data points, as well as see the respective trends at glance. The students were able to develop their skills in using equipment and/or computer programmes. The equipment and the programmes enabled them to organise and analyse their data. They were thus able to interpret their data. In fair testing investigations, they developed the ability to transform their results into workable forms that enabled them, for instance, to graph their data, determine patterns in the data, explain relationships and/or observations in terms of their previous experiences, and draw conclusions. In pattern seeking investigations, advanced computer programmes (p. 227) and mathematical formulae (Chapter 4, p. 173) were used for data transformation and the associated data analyses, which involved statistical computation, in the students' quests to deduce the patterns in data. The students were also able to search for explanations of the data. In general, with their data interpreted and new knowledge developed, the Expo students could also communicate their science information (Chapter 4, Tables 4.1a, 4.1b–4.5a, 4.5b).

The findings of this study were similar to those of a study by Griffiths and Thompson (1993) in which the understanding of the meaning of a range of science processes of Grades 7 and 10 students in Canada were examined. Seventy–five percent of the 32 participants were able to interpret the data provided to them. Furthermore, findings similar to those of the current study were found in So (2003) and Molefe (2008). So (2003) discovered that primary school students could gather and make sense of data. She also found that they could represent their data well, and analyse the data, and draw conclusions. Molefe (2008) discovered that the Expo student he studied (p. 234) showed proficiency in working within scientific parameters. This was evident in the student's ability to interpret her observations and her numerical data, and make proper calculations related to phenomenon investigated with a potometer. However, the student was unable to perceive and state a relationship between two variables, construct a statement to describe a relationship between two variables, and draw inferences from her information.

The Expo students also faced challenges. Contrary to the challenge mentioned by Griffiths and Thompson (1993) (Canadian students who were proficient in interpreting data failing to explain the meaning of interpreting data), they failed to articulate during the interviews *how* they interpreted the data in their projects. One Expo student summarised what she noticed from her data: "…it all was intellect" (Alina, personal interview, August 2007). Another student (Chapter 4, pp. 169-170) failed to describe how she went about arranging and/or analysing her data. She merely focused on how she gathered her information. In another interview, a student could not even state how her information/data enabled her draw conclusions. She simply answered that the information showed that her method had potential (Gertrude, personal interview, August 2007). Furthermore, the Expo students were unable to interpolate for missing data, supporting previous findings by Beaumont–Walters and Soyibo (2001) and Molefe (2008). However, the students' experiences and research–based knowledge enabled them draw inferences from their information. For instance, Henry's interpretation or explanation subsequent to his observation that his friends had asthma was that their condition was due to allergies. Consequently, he was able to predict that rhinitis would be the most common allergy.

The findings of this study show that resources, such as scientific equipment and computer programmes (pp. 227; Chapter 4, pp. 133, 187) play an important role in enabling Expo students to successfully interpret data that demanded extracting information from graphs and tables. The students may be able to identify patterns or trends from both first–hand and second–hand data. This contradicts Schauble, Glaser, Duschl, Schulz, and John's (1995) view that students often have difficulty in identifying patterns or trends from such data. However, the students were challenged when asked to provide accounts of how they interpreted the data in their respective projects. The challenge supports the link between students' abilities to interpret and to communicate, and that "both communicating and interpreting are cognitive in nature" (Kok–Auntoh & Woolnough, 1994). Expo students should therefore be assisted not only to produce an impressive piece of work in reports but also to describe or explain the basic components of their interpretation. These components may include, for example, interpolating missing data, data–related observations, how they decided on the arrangement and analyses of their data, and how drawing conclusions was made possible.

According to DoE (2002), knowing how to get information from a book and learning from the printed page are also essential parts of interpreting information. The associated skills may include cross–referencing in books, finding information from knowing how a book is structured, and organising information using summaries or concept maps (DoE, 2002). The Expo students were able to access background information from different sources (p. 226). They could gather information from the Internet and organise and summarise it. This study supported previous findings by So (2003) and Molefe (2008). Moreover, the South African science curriculum shows that the process skills that students "develop and use in the Life Sciences [such as, for instance, interpreting information] allow them to solve problems, *think critically*…[as they investigate phenomena to] find answers and satisfy their curiosity" (DoE, 2003b, p. 10; emphasis added). In Gertrude's case, the gathering of the information involved critical examination of a website, and evaluation of the quality of its contents before her findings were interpreted (Chapter 4, p. 161). This contradicts Lorenzen's (2001) conclusion – based on high–school students' use of the Internet for research in the United States – that a critical look at website information is a problem for students. Lorenzen's (2001) conclusion was further contradicted by the current study's finding, in which Felicia's critical research (Chapter 4, p. 109) provided another illustration of an Expo student's ability to think critically.

Predicting. This skill may involve a student in using knowledge to decide what will happen if something is changed in a situation. It includes predicting from patterns in information, or interpreting a model of a system to predict how a change in one variable will cause a change in another variable (DoE, 2002). In simplified terms, the student may estimate or forecast future observations or occurrences on the basis of present trends or previously known information (Horton & Hutchinson, 1997; Chiappetta, 1997). McPherson (2001, p. 243) further explained that "in contrast to hypothesis testing, experimentation generally is not required to assess predictions: *predictions require observation*, potentially aided by technology, but *they do not require use of the 'scientific method'*" (emphases added).

The current Expo students were able to draw upon relevant *knowledge* constructed from observed patterns in research to successfully estimate future observations in terms of, for instance, conditions and/or diseases under study (e.g., Chapter 4, p. 134). This finding is consistent with Hurst and Milkent's (1996) study in the United States with Grade 10 biology students. The students' ability to retrieve relevant knowledge from memory, especially at formal or transitional stages, was among the determining factors for their successes in prediction. Lavoie and Good (1988) have also argued that high–school students taking biology had their success in the skill embedded in an initial knowledge about the topic of interest. Furthermore, Expo students' *experiences* with the phenomena investigated (Chapter 4, pp. 101, 117) were of vital importance in their success as well. The findings supported results from McNay and Melville's (1993) study on elementary students' skills in making predictions and their understanding of what prediction meant. The findings of the present study suggest that the key factors that shape Expo students' ability to predict are their knowledge and experiences related to the biological phenomena investigated.

As referred to earlier, Expo students should have observed patterns in research in order to successfully estimate future observations regarding their respective phenomena under study. However, there were incidents in which Expo students' responses to the questionnaire were based on the designs of the investigations (Questionnaire responses: Felicia and Gertrude). This was congruent with Hurst and Milkent's (1996) findings on "unsuccessful predictors" (p. 548). Those who appeared to possess relevant content knowledge that could form the basis for prediction (Hurst & Milkent, 1996) also had misconceptions and rarely reviewed their answers for inconsistencies. Hence, the findings of this study suggest that it is essential to develop students' conceptual understanding of predicting at school. Lavoie and Good (1988) and Hurst and Milkent (1996) suggested improvement of students' prediction skills through guided practice and experience. After all "improving prediction problem–solving skills can lead towards a greater understanding, application, and appreciation of science and the scientific process" (Lavoie, 1993, p. 781), which may include hypothesising.

Hypothesising. This skill is “a prediction that answers the research question” (Lipowski, 2008, p. 1669). Millar (1988) argued that hypothesising falls under those skills that are very much part of our everyday life. He reasoned that the fact that we rely on our observations and past experiences to make future predictions justifies his assertion. In Millar’s (1989) view, “the complexity and sophistication of the data base and conceptual ideas” (p. 56) are what differentiate a child’s hypothesis from that of an experienced scientist. The hypothesising skill may involve a student in naming possible factors which could have an effect on a situation, giving reasons why something has happened, stating a reason or cause for something, or using prior knowledge as well as information given in the task (DoE, 2002). In short, people hypothesise when they make a testable assumption of a relationship between factors (i.e., variables) in a given situation, and the subsequent explanation (framed from evidence, observations, prior knowledge and past experiences) for that relationship. Hence, unlike in predicting, students are hypothesising if they make “a tentative generalization, which is subject to immediate or eventual testing by one or more experiments, to explain a relatively large number of events” (Horton & Hutchinson, 1997, p. 31). Thus, it cannot be argued that hypothesis testing has taken place, if one’s research merely describes patterns regarding phenomenon under investigation, without testing the mechanisms underlying the patterns (McPherson, 2001).

In this study, a clearly stated hypothesis was absent in one *project report*, although the student concerned (Alina) had clearly stated the variables to be tested. Nevertheless, research (on blood glucose levels, video games, HRT and breast cancer, biometric identification methods, and allergies) and experience (with video games, pollen and dust) provided the basis for the prior knowledge the Expo students needed to make testable assumptions. Whether variables and/or causal factors were explicitly stated in the Expo reports (as in fair testing) or otherwise (as in pattern seeking), a link between observed phenomena and specific variables and/or factors was evident (Chapter 4, pp. 134, 207). This study suggest that Expo students may show considerable success *in their Expo reports* in the skill of hypothesising, and that the testable assumptions made were framed around their research and experiences related to the phenomena investigated (e.g., Table 4.2a, p. 155; Table 4.5a, p. 210).

However, the Expo students (with the exception of Henry) could not provide explicit explanations for the relationships/patterns between variables and/or causal factors. The researcher had to deduce explanations for the relationships between variables from the information presented in their Expo reports. For instance, Alina's explanation for the relationship between the glucose levels and exercise, and her belief that exercising causes a drop in blood glucose levels by using up the glucose in circulation, proved useful. Furthermore, with regard to the pattern seeking type of investigation, one student's ability to hypothesise exceeded the science curriculum standard (Chapter 4, p. 210). However, a response *in the questionnaire* was obscure and incorrect: "I presumed that there was a basic need to know about allergies and what causes/affects/relates to them" (Chapter 4, p. 207).

The finding of this study (of an obscure and incorrect response) supported conclusions in Millar and Driver (1987), Germann, Aram, Odom, and Burke (1996), and Beaumont–Walters and Soyibo (2001). In the Germann *et al*. (1996) study on primary school students in the United States, "less than 50% of the students performed successfully" (p. 200) on hypothesising and the other skills analysed. In particular, they discovered that "the responses of the majority of students were incomplete, ambiguous, and/or incorrect" (p. 200). They also reported their thoughts about the reasons behind the students' substandard performance:

> Some students may be able to perform experiments well but lack the communication skills to be successful when written responses are required. Classroom experiences teachers provided for their students to learn processes may have involved step–by–step procedures that were given to students to follow in "cookbook" fashion so that they had little opportunity to practice the processes themselves. (p. 200)

Indeed, Millar and Driver (1987) showed that, even where investigations were conducted within scientific parameters, the outcome of the students' cognitive immaturity might be hypotheses "which differed from those of accepted science" (p. 49).

Poor results, especially in formulating hypotheses (the mean score was 32.80%), were also found in Grade 10 students in the Jamaican study (p. 237). The students were not successful because they had not been exposed to hypothesising and were not cognitively mature enough to handle the skill (Beaumont–Walters & Soyibo, 2001).

This study suggests that, while Expo students may show considerable ability in hypothesising, they may also be cognitively challenged when written responses are required, especially in pattern seeking. More support and guidance are therefore needed to hone the students into problem–solvers who can appropriately hypothesise. Indeed, Oh (2009) concluded, on the basis of his findings, that "students in the secondary school can formulate scientific hypotheses [well] when they are given appropriate guidance and support" (p. 17).

Raising questions about a situation. This skill may involve a student thinking of questions that could be asked about a situation, recognising a question that could be answered by scientific investigation (as opposed to one which science could not answer), or rewording the question to make it scientifically testable (DoE, 2002; Devereux, 2000). This skill occurs in tandem with observation and hypothesising because predictions are normally generated from formulated, testable questions, which in turn are based on observations (Figure 5.1). All these elements are essential parts of planning an investigation (see DoE, 2002).

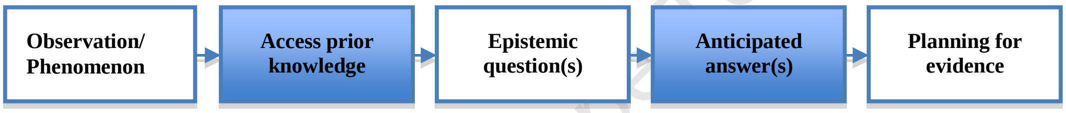

Figure 5.1. Sequence of cognitive activities in the pre–experimental phase. From Neber and Anton (2008)

The current Expo students were able to state the aims of their investigations *in their Expo reports*. However, only a few clearly stated their formulated research problems or research questions in their reports. The same results were found in So (2003). However, evidence from the interviews showed that all the students raised questions about a situation (Chapter 4, pp. 135, 152, 171, 190, 207). The questions were framed around factors relevant to them (diabetes, video games and blood pressure, HRT and breast cancer, allergies). Indeed, Arena (1996) emphasised the importance of relevance in the development of students' integrated process skills. The issue of relevance regarding questions raised by the Expo students also confirmed that the process of problem–discovery could be rooted in factors relevant to the students (Chin & Kayalvizhi, 2002). Students should therefore think about questions that relate to their daily life when planning science projects (Thompson, 2006).

The findings of this study suggest that teachers may sharpen their students' ability to develop this skill by concentrating on problems of personal relevance to the students. Moreover, Expo students may be more comfortable with aspects of their investigations (for example, background research [Chapter 4, pp. 144, 191]), rather than raising questions about a situation. Certain factors might contribute to the evident flexibility in their designs (i.e., starting with the research). Identifying and formulating research questions has proved challenging for students, even in collaborative settings (Colley, 2006).

Thompson (2006) pointed out what could be a major challenge related to raising questions: "The question must be testable, measurable, and repeatable" (p. 8). The students in this study claimed that they had addressed these. However, some of the research questions formulated were in fact broad statements. For example, *"What causes ... [blood glucose] levels to drop?"* (Chapter 4, p. 135) instead of "*How does exercise and fasting affect a person's blood glucose levels*?" The broad statements were expected during the interviews, as Germann's *et al.* (1996) study also showed that students might struggle with formulating testable questions. Nevertheless, the students in this study reported several measures taken to produce testable questions. For instance, in projects focusing on *fair testing* (Alina, Elizabeth), carrying out tests or piloting the studies were reportedly used to make the statements worth investigation. In projects focusing on *pattern seeking*, questions on the data collection instruments (Felicia), research (Henry), or research and brainstorming (Gertrude), were reported.

This study suggests that students need more guidance and support in order to raise questions which can be answered through scientific investigations. Furthermore, the development of this skill could be marred by challenges and misconceptions, especially in pattern seeking. For instance, students might be cognitively challenged in terms of describing how to make questions scientifically testable. Bishop (2000) suggested that teachers provide students with the opportunity to verbalise their research questions and obtain a clear focus prior to collecting information.

Planning and conducting science investigations. The skill of planning science investigations is an Assessment Standard (the minimum requirement expected of a student in order to progress to the next grade [DoE, 2003b]) in which a student is expected to be able to reword a vague question to make it into a testable prediction, deciding which variables matter in the problem or question, planning how to change one variable and keep the other variables constant (controlling variables), planning which variables to measure and how to measure them, knowing how to improve the accuracy and validity of the measurements, drawing inferences from results (their own results or someone else's results), and evaluating someone else's plan for a fair test (DoE, 2002). In short, planning involves defining the problem, identifying the variables to be manipulated, considering how observations will be utilised to address the problem, deciding on suitable tools and materials, giving careful consideration to the order of working, and deciding on methods for recording results and findings (Devereux, 2000).

Students' plans and designs normally involve utilising certain types of investigations (So, 2003; Chapter 4, p. 162). In this study, *pattern seeking* dominated (Chapter 4, pp. 162, 180, 198) over *fair testing* and *fair testing and comparing* (Chapter 4, pp. 127, 144), with only one Expo project involving more than one type of investigation (Chapter 4, p. 162). These findings differ from those of Watson, Goldsworthy, and Wood-Robinson (1999) and So (2003). A study in Wales and England, in which over 1000 investigations were classified by primary school teachers, showed that fair testing dominated and that there was very little pattern seeking (Watson *et al*., 1999). On the other hand, in So's (2003) study, making things dominated projects performed by the students, with some projects encompassing more than one type of investigation.

This study suggests that more sophisticated pattern seeking and fair testing types of investigations might dominate students' projects in Expo categories related to Life Sciences. Two aspects may be deciding factors when the students plan their investigations: (a) The resources and facilities at the students' disposal (pp. 225-227), and (b) encouragement (by mentors) to pursue the types of investigations considered to maximise students' chances for success at Expos (e.g., Chapter 4, p. 106; supported by Pyle, 1996).

Expo students tend to plan their scientific investigations around a problem or a question of interest they feel needs to be addressed (p. 222). Indeed, in Tytler and Swatton's (1992, p. 28) and Tytler's (1992, p. 406) studies based on case studies of independent research projects by secondary school students, all "the students started with a problem born out of their own experiences [or interests] and adopted procedures to solve that problem". Hence, it makes sense when Bishop (2000) suggests that, within the context of independent research projects, students should be trained to explore a problem or a question of interest, focusing on it rather than selecting a topic.

The designs by the Expo students of tests or surveys to investigate variables, and their evaluations of the designs exceeded DoE's (2003b) standard for a given grade (e.g., Table 4.2a, pp. 155-156; Table 4.3a, pp. 174-175). However, only one Expo student planned around a question concerning a phenomenon observed in order to generate ideas for her investigation (Chapter 4, pp. 113, 171). Other Expo students either concentrated on *understanding a scientific report* (Chapter 4, p. 127), conducting *background knowledge/research* (Chapter 4, pp. 144, 191), or coming up with an *aim of a study* (Chapter 4, p. 208), prior to stating their problems/questions and formulating hypotheses.

The findings suggest that Expo students tend to focus on factors (e.g., research and aims of their investigations) other than problems or questions at the beginning of their investigations. This flexible use of the scientific method is acceptable because scientists themselves only rarely follow this method during investigations (Robertson, 2007). However, it is not only recommended but of fundamental importance that students are made aware that framing an initial problem or question is critically important as the focus of their investigations. As Roth and Roychoudhury's (1993) study showed, with refined questions, students showed proficiency in clearly defining the variables to be tested.

Planning around variables which could be tested, whether independent, dependent variables and controlling variables (*fair testing*), or dependent variables and possible causal factors (*pattern seeking*), is also essential at the planning stage of an investigation. In this study, Expo students' reports showed that they were able to identify either independent, and dependent variables and control variables (e.g., Table 4.1a, p. 139), or dependent variables and causal factors (e.g., Table 4.5a, p. 210). The students could decide how to observe and measure the variables (e.g., Chapter 4, p. 139), selecting large enough samples to provide reliable data (e.g., Chapter 4, p. 210). However, the identified and classified variables were only stated in the Expo reports of projects focusing on *fair testing*. The findings of the present study support So's (2003) and Roth and Roychoudhury's (1993) findings, but *not* Beaumont–Walters and Soyibo's (2001). Beaumont–Walters and Soyibo (2001) showed that the Grade 10 students they studied were unable to successfully identify variables. As was the case with hypothesising (p. 246), they reasoned that these Grade 10's shortcomings regarding identifying variables were due to the students' lack of exposure to the skill, and their lack of sufficient cognitive maturity to handle it. On the other hand, Roth and Roychoudhury (1993) found that Grade 8 science students, and Grade 11 and 12 Physics students, were able to develop identifying variables and other high–order process skills over a period of 14 months. The development was "also for weaker students" (p. 148). In So's (2003) study, the students' proficiency in identifying variables also included the use of a control.

The results of the current study suggest that skills, such as planning investigations in terms of the variables and causal factors to be used, can be developed within the context of an expanding framework of knowledge (i.e., Expos). However, the findings also suggest that students planning fair tests may find it easier to identify and classify variables to be used than those who plan to deduce patterns in their data.

When planning around the variables and the factors, students are also expected to decide on suitable tools and materials and methods of recording their results and findings (p. 136). The Expo reports showed that students learning through Expo projects may exceed curriculum expectations. Designs of their investigations may include sophisticated electronic equipment and computer programmes, and/or procedures (e.g., Chapter 4, p. 175). The designs may also include identified suitable forms of data representation, such as graphical and tabular displays and photographs (p. 237). They may thus develop valuable technological skills while conducting their investigations (p. 227).

Kok–Auntoh and Woolnough (1994) argued that "how well students plan will determine how well they perform [the practical part their investigations]" (p. 36). Conducting investigations is an Assessment Standard in the South African science curriculum (DoE, 2002). It is also a skill in which a student is expected to be able to set up a situation in which the change in the dependent variable can be observed, while controlling the interfering variables, measuring all the variables, recording data, interpreting the data to make findings, and reporting in qualitative and quantitative terms (DoE, 2002). The above expectations further reinforce a narrow perception by DoE (2002) that *fair testing* is the type of investigation that best describes process skills (p. 241). Indeed, Tytler and Swatton (1992) also observed that there has been more emphasis on the fair testing type of scientific investigation even though there are other more interesting types. They warned that this biased view of scientific investigations might have a negative impact on students' motivation and interest, especially in relation to certain areas of learning. Contrary to DoE's (2003b) narrow perception regarding conducting an investigation, students' proficiency in the skill should be evident when they meticulously collect and record qualitative observations and quantitative data; use advanced techniques associated with interpretation of data;

collect complete and pertinent data essential to addressing their research question; state the problem, hypothesis or relationships; and communicate their findings.

As stated previously, the manipulation of variables is at the core of conducting investigations. Hence, it essential that students plan around these subskills (Beaumont–Walters & Soyibo, 2001; Huppert *et al.*, 2002; Roth & Roychoudhury, 1993). In this study, Expo students who conducted fair testing types of investigation (Tables 4.1a, 4.2a) were able to set up a situation in which change in the dependent variable could be observed, while controlling the interfering variables and measuring other variables. The variables and the practical procedures associated with their manipulation were explicitly stated in the students' Expo reports. Their "fair tests" were described in terms of extraneous variables, and were accompanied by impressive evaluations of their well–executed research designs. The methods of collecting and recording their qualitative observations and qualitative data and the associated data interpretation were meticulous and sophisticated. For instance, they used sophisticated electronic equipment in their quests to address either their statement of the problem, their hypothesis or relationships, and make findings prior to communicating these in qualitative and quantitative terms.

The students' sophisticated approach to conducting investigations was particularly evident in the pattern seeking types in which surveys (Tables 4.3a-4.5a) – other than use of sophisticated equipment (Topcon Fundus camera excluded [Chapter 4, p. 175]) common in fair testing types – were part of well–written practical details of the procedures used. The students' proficiency in conducting investigations was thus evident. This was expected since *all* the Expo students had clearly stated the aims of their studies – a phenomenon that, according to Gomes, Borges, and Justi (2007), plays a significant role in planning and conducting investigations. The students were able to use surveys to collect complete and relevant data essential to addressing their respective hypotheses, problems, relationships or research questions. Apart from meticulous collection and recording of information, they used advanced methods and techniques for organising, representing and manipulating data to make meaning (e.g., Chapter 4, p. 175). Hence, it was no surprise that there were instances where the projects even exceeded the standard stipulated in the South African curriculum. For example, in one case study of a Grade 10 student, a Topcon Fundus camera and mathematical formulae were used to collect data regarding her participants' Fundi, as she conducted her surveys. She also used a programme in "Paint" to analyse her data. The programme enabled her take accurate measurements of her subjects' Fundi in order to compute their Fundus ID numbers using the mathematical formulae. She was able to critically analyse, reflect on and evaluate her findings both on her own and when requested. She recognised the need to repeat and check her measurements and select suitable measuring techniques to establish trustworthiness in her data.

As referred to earlier (p. 245), the variables manipulated were not explicitly stated in pattern seeking types. However, extraneous variables were evident, and were utilised to report on procedures taken for fair testing during the interviews. The reported procedures also included answers such as, for example: "Um…giving everybody the same survey".

The present findings corroborate Huppert *et al.* (2002), and Tytler and Swatton's (1992) findings but not necessarily those of Saat (2004). Henderson (1973) long argued that adequate control of variables constituted one of the major problems in high–school students' development of independent research projects. Indeed, Saat (2004), in a case study in which he examined the process of acquisition of controlling variables among grade five students, found that controlling variables and conducting fair tests were cognitively demanding and therefore required more practise and time. Tytler and Swatton (1992) also argued that dealing with variables could be challenging for students. They discovered that, even though the students observed were expected to address variable control, it was explicit only in some. However, regardless of the students' flaws, they were able to come up with experimental designs that exceeded curriculum standards in the United Kingdom. In a study conducted in Israel in a cognitively challenging environment (p. 240), the experimental group at transitional stage, compared to the control group, performed well in controlling variables and in other challenging skills (Huppert *et al.*, 2002).

It should be noted that students may be cognitively and procedurally challenged in terms of designing their investigations in order to test their hypotheses, and analyse the evidence. The challenge may also include understanding how to design and implement fair tests or control the variables associated with pattern seeking. Furthermore, recognising the role of measurements and errors in their investigative work, as well as data interpretation prior to communicating their assembled science information also poses challenges. This study's findings on the two process skills suggest that if teachers are prepared for the abovementioned challenges, students learning through Expo projects may have ample potential to make exceptional designs and conduct their investigations. Teachers' preparations may include creating an appropriate experience for their students, which may tap into their metacognitive awareness (Mbano, 2004). Indeed, Roth and Roychoudhury's (1993) study showed that, at secondary level, students who were granted an opportunity to choose research topics and design their own experiments were very proficient, not only in planning investigations but also in conducting them. It was discovered that "they successfully chose their equipment, methods of data collection, and subsequent analysis" (p. 141). These students' proficiency was rooted in a support mechanism that encompassed cooperative learning and facilitation by their teachers.

Overview of Expo participants' developed Life Sciences knowledge

The purpose of the South African Life Sciences curriculum is to develop students' proficiency in scientific skills so that they will be able to use them to interpret and use *Life Sciences concepts* in explaining phenomena (DoE, 2003b). It is believed that through students' exposure to the concepts and processes in the Life Sciences, *construction of new knowledge* can be promoted. The curriculum also shows that it is important that the students not only strive to understand the concepts and processes, as well as their application in society, but should also be able to reflect on their learning experiences as they engage in *critical inquiry* (DoE, 2003b). Indeed, So (2003) showed that the following educational outcomes can be realised when students learn through investigation projects: (a) Interplay between the students' understanding of scientific concepts and the details of their performance regarding process skills, (b) the students' feelings and thoughts about the process of scientific investigation, and (c) proficiency in showing the applicability of science to their everyday life.

Hence, in this sub–section I focus my discussion on the Expo students' Life Sciences concepts, while I also explore their understanding of scientific investigations. Several studies have shown that investigation projects or activity–based learning provide a context for the construction of new knowledge using scientific skills (Molefe, 2003, 2007, 2008; So, 2003). Furthermore, I explore the students' proficiency in applying Life Sciences knowledge, as the kind of students who are envisaged in the Life Sciences curriculum (DoE, 2003b, p. 9) should be able to "*apply scientific knowledge* in their personal lives and as responsible citizens *in ways that will contribute to a healthy lifestyle* and the sustainable management of resources" (emphases added).

As stated elsewhere (p. 242), interpreting information was one of the challenges associated with the current Expo students' development of Life Sciences knowledge. However, the students' projects provided details of their performance regarding process skills, which not only enabled them to interpret pertinent health/medical concepts and draw conclusions based on evidence collected but also to provide scientific explanations based on biological phenomena (Tables 4.1b-4.5b, pp. 142, 160, 178, 197, 214).

Similar findings were found in Molefe (2003, 2007, 2008) and So (2003), but not by Hattingh, Rogan, Aldous, Howie, and Venter (2005). So (2003) showed that students learning through investigation projects might not be able to interpret pertinent scientific concepts. However, her discussion showed that this shortcoming might not hinder their proficiency in providing appropriate scientific explanations. She believed that the students became proficient in constructing science understanding in the process of investigation, as they developed their scientific skills. In Molefe's (2003) study, in which students in Cape Town investigated water retention and drainage in soils in the context of the then new Natural Sciences curriculum, quantitative and qualitative results showed that both secondary and tertiary students successfully constructed scientific knowledge, with higher gains in process skills development and attitudes to science also evident. The success of the students' construction of knowledge regarding soils was also evident in two Expo projects, which were also explored in the study (Molefe, 2003). On the other hand, Hattingh, *et al*. (2005) found that secondary students' performance in learning outcomes stipulated in the *C2005* Natural Sciences curriculum was below par in Mpumalanga province. This followed from an examination of the Mpumalanga Secondary Science Initiative, which sought to improve the teaching and learning of mathematics and science in all secondary schools in Mpumalanga over a period of three years. In a study in which Molefe (2007) examined educational outcomes of two students who investigated two model boats, the students showed proficiency in the attainment of a selected learning outcome for the study – Learning Outcome 1. In Molefe's subsequent study (Molefe, 2008), the results showed that Expos could facilitate the student's competence with respect to the development of Life Sciences concepts.

It should be noted that students studying Life Sciences are expected to show proficiency in making decisions using *critical thinking skills* (DoE, 2003b). The current Expo students not only identified and solved problems but also made decisions using critical thinking skills. These skills were evident in their evaluations of the research designs and plans of their studies when they were requested. The following were recognised: The need to increase the number of participants (Chapter 4, p. 175), and the length of an investigation's duration (Chapter 4, p. 194); the use of a few case studies which encompass actual tests (Chapter 4, p. 210); additional research (Chapter 4, p. 139); including tests associated with gender and race (Chapter 4, p. 156); or the introduction of a new analytical tool/programme (Chapter 4, p. 175). All the students were able to evaluate their questions in the light of the outcomes of their studies, stating questions that should have been raised on the basis of improved designs of their studies. These reflect "students' consistency in finding solutions to the problems posed by individual investigations" (Kok–Auntoh & Woolnough, 1994, p. 38). The use of critical thinking skills was also evident in the critique of information obtained from different sources (p. 243; Chapter 4, pp. 161, 181). However, different results were found in Molefe's (2008) study, in which the student concerned was unable to develop her critical thinking and scientific reasoning. Nevertheless further research is needed to substantiate Molefe's (2008) findings.

The findings of this study suggest that, although Expo students may not articulate in detail how they interpret data, they can provide appropriate scientific explanations or reasoning, and critically evaluate not only elements of their investigations but also information they have obtained from other sources.

DoE (2003b) prescribed different methods and/or sources for students to access information (books, magazines, making use of libraries, clinics, medical personnel, Internet). Expo students were able to access relevant knowledge to explain phenomena under investigation from Internet and books/encyclopaedias (p. 226) than other sources observed, namely journals, magazines, pamphlets, and research posters. Similar results were found by So (2003) and Tytler (1992). The students So (2003) studied acquired new knowledge from books and the Internet, while Tytler (1992) discovered that books were the main source of theoretical knowledge of the students he studied.

It appeared from this study that the current Expo students needed a broad theoretical base for practical knowledge gathered for their Expo projects (knowledge that served a particular purpose, for example, health promotion [e.g., Chapter 4, pp. 101, 109] and/or genetic engineering [Chapter 4, pp. 115]). Such a knowledge base was created through background research in the Internet and books. The students also had to supplement the information from the Internet and books with information that could enable them understand specific scientific concepts in their quest to construct new Life Sciences knowledge that could provide viable solutions. Hence, they used additional secondary sources (e.g., pamphlets for medical conditions or diseases).

The investigations' results and the conclusions made by Expo students, as well as previous experiences and learning, also contributed to their construction of the new knowledge. Certain Life Sciences concepts are essential for school students to understand the phenomena investigated (DoE, 2003b). Indeed, Elizabeth emphasized the important of grasping concepts when learning Life Sciences (Chapter 4, p. 105). The key health concepts the Expo students developed were embedded in either health conditions or disease (e.g., diabetes, menopause, breast cancer). They included glucose homeostasis and insulin production and treatment (Chapter 4, p. 142); causes and symptoms of allergies (Chapter 4, p. 214); blood pressure (Chapter 4, p. 159); Hormone Replacement Therapy (HRT), side effects and symptoms, disease, and treatment (Chapter 4, p. 197); and the scientific concept of using digital retinal images from a specialised camera for biometric identification (Chapter 4, p. 178). Similar results were found in So (2003) in which students were able to develop scientific concepts such as, for example, water diffusion, and air pressure. The findings of the current research suggest that the study of the Life Sciences through Expos provided a springboard from which Expo students were able to explore health concepts essential to their understanding of the different phenomena investigated, and to construct new knowledge in Life Sciences.

The Expo students' new knowledge was supplemented with knowledge from various human resources which encompassed professors, doctors and family members in pertinent fields (p. 225). So's (2003) and Tytler's (1992) studies showed that only a few students use human resources. Nevertheless, the present study suggests that information the students collected from pertinent human resources also plays a major role in the construction of new knowledge in Life Sciences.

It should be noted that the systematic study of life is not limited to students' understanding of concepts and processes and their application in society, when questing for new knowledge in Life Sciences. It involves reflection as well (p. 254). In this study, Expo students reflected upon science and/or scientific investigation. Expo students found scientific investigation demanding, yet rewarding (e.g., Chapter 4, p. 144). Similar insights were found by So (2003) and Tytler (1992). Hong Kong primary school students "found the process of scientific investigation demanding but fruitful” (So, 2003, p. 192). Likewise, the students studied by Tytler (1992) perceived scientific investigation as challenging. However, they also felt that such investigations provided opportunities and a broader scope in learning science, to which they were not exposed in a normal classroom. In this study, Expo students elaborated that scientific investigation requires hard work (Elizabeth [Chapter 4, p. 144]), determination, interest and effort (Felicia [Chapter 4, p. 180]) exercised over a prolonged period of time, as well as impeccable execution (Felicia, Henry, Gertrude [Chapter 4, pp. 162, 180, 199]). Moreover, certain Expo students perceived investigations and/or science as vehicles for learning more about health concepts related to “medical knowledge”, such as HRT (Felicia [Chapter 4, p. 180]), or new scientific skills together with concepts, such as blood pressure (Elizabeth [Chapter 4, p. 100]). Indeed, So (2003) also argued that students’ reflections on learning experiences through scientific investigations might encompass shared understanding of scientific concepts in a community of learners. Some of these concepts might not be provided at classroom level because knowledge developed through extended scientific investigations is, *inter alia*, practical and serves a particular purpose (Tytler & Swatton, 1992; supported by Expo students [p. 259]). Consequently, scientific investigations may also be productive in creating awareness of challenges, as well as confronting pressing problems, such as diseases and medical conditions.

Alina showed that scientific investigations enabled her to develop her ability to compile her scientific reports, recognise “different aspects of science”, and use the scientific method in her investigation. In my opinion, Alina provided elements that constitute the nature of science. As Woolnough (1994) eloquently puts it, scientific investigations, apart from exciting school students’ interest in science, may actually show them what science is like. Alina’s reflection on scientific investigations may sum up the perceptions and understanding of the nature of science by Expo students and “their non–specialist mainstream classroom counterparts” (abstract) in Parker and Rochford’s (1995) study in Cape Town. These Expo students understood science to be about discovering something new about our surroundings and the universe. On the other hand, they also perceived the scientific method to be all about questioning, hypothesising, collecting data, and concluding, with the majority considering careful recording of results playing a major role in the description of this method.

Scientific investigations may also enable students to develop conventional values and attitudes perceived to be closely related to learning science. In the current study, these aspects were more pronounced in certain students' (Gertrude and Felicia) reflections on the process and product of scientific investigation, and the skills they believed they had learnt during their investigations. In one case, a concerned student (Felicia) thought scientific investigation was a process that started with passion (Chapter 4, p. 180). However, it needs proper organisation and management, and because of its complexity, requires determination and interest. Felicia also exhibited an attitude common to scientists as she reported on the skills she had learnt. A scientific attitude that embraced a systematic and logical approach and critical–mindedness was evident in her Expo project. Similar findings were found in So (2003). The findings enabled So (2003) to argue that students' reflections on their learning experiences might also include values embedded in science and attitudes perceived to be closely related to learning science. The outcomes of such values and attitudes could be meaningful learning experiences for students, marked with satisfaction and joy (Tytler, 1992).

Apart from their reflection on investigations, students are expected to show "an understanding of the application of Life Sciences knowledge in everyday life" (DoE, 2003b, pp. 26-27). The Expo students held a conventional view that Biology is not a practical subject (e.g., Chapter 4, pp. 96, 105, 114). They were, however, able to present contributions made by their studies in their Expo reports (e.g., Felicia, Henry). All the projects contributed to solving problems related to conditions and diseases (blood pressure and prehypertension, diabetes, breast cancer, allergies, Retinal Fundus Biometric Analysis for diabetics and for identification of young children) for the purpose of *health promotion* and/or *genetic engineering.* Similar findings were recorded in So's (2003) study in which the students' projects helped in solving problems such as, for instance, "filtering fresh air" (p. 191).

Scientific investigations may offer strategies and frameworks for deepening Expo students' understanding of scientific concepts, which cognitively challenge their imagination. However, teachers should also anticipate that students might be challenged by these enterprises. Indeed, one student's reflections regarding scientific investigations suggested that success in such investigations lies in positive attitudes (p. 259). Thus, developing students' proficiency in providing appropriate scientific explanations and relevant applications of concepts learnt in everyday life, in addition to skills, might not be the only outcomes when students do science through investigations. Scientific investigations might elicit *passion*, *determination* and *interest* in their work. These should perfectly complement scientific attitudes common to scientists, such as a *systematic and logical approach* and *critical–*

mindedness, when the students conduct their investigations.

Conclusion

ESKOM Expos provided the students in this study with opportunities to pursue ideas about real challenges and problems of personal relevance and interest in South Africa, using investigative projects (p. 222). The Expos set a stage in which the students could develop their proficiency in scientific skills within the context of an expanding framework of knowledge. Specifically, they were exposed to all or some of the eleven process skills stipulated in the Natural Sciences, *depending* on the type of each investigation. Furthermore, because their projects were embedded in Life Sciences, critical inquiry, reflection on their investigations, understanding pertinent concepts and processes and their application in everyday life (DoE, 2003b) should have constituted key elements of their individual, systematic studies.

Scientific skills

Roth and Roychoudhury's (1993) open–inquiry science programme showed that students could successfully develop science processes when the problems examined were relevant to them. This was substantiated in the current study, with the results showing that Expo students had sufficient proficiency in developing the curriculum–bound process skills applicable to their respective investigations, as well as critical thinking and inquiry skills. However, while all the Expo students could state their aims, only one student could *clearly* state the focal research question or research problem in her Expo projects. Hence, it was no surprise that virtually all the projects' plans were not framed around a question. Although the students' research processes in the Expo reports were satisfactory overall, evidence from the students' interviews and questionnaire further suggested that science teachers might be confronted with pedagogical challenges with respect to process skills, especially when students are required lucidly to present descriptions of certain components of their completed projects. These challenges may include:

- Misconceptions, particularly in *measuring*.
- Students' lack of success in understanding what "forms of *recording information* and *communicating science information*" mean, and the subsequent classification of the "forms" in terms of the degree of their complexity.

- Students' inability to set and/or articulate rules for *classification* of a phenomenon under investigation.
- Students' inability to provide articulate accounts of the basic elements of *interpreting data*, which are embedded in their respective investigative work, for instance, how they arranged and analysed their data.
- Students' ambiguous and incorrect descriptions associated with *predicting*, *hypothesising*, and *raising questions about a situation*.

In short, despite the Expo students' adequate proficiency in scientific skills as reflected in their Expo reports, they were challenged with respect to the *descriptions* of some of the scientific skills they developed. The researcher's personal observations during the study led him to conclude that the findings reflected Expo students' limited *understanding* of the questions and/or concepts presented to them, rather than of the "processes" of the skills. For instance, despite the misconceptions Expo students had with regard to measuring skill, their ability to measure quantities – especially in projects focusing on fair testing – was credible. What was questionable was the students' understanding of the concept of the scientific method in relation to the process skills. For instance, those students who started their investigations with research or background knowledge (e.g., Chapter 4, p. 144) should have responded that they developed skills in communicating science information or analysing investigations during the interviews.

Life Sciences knowledge

In the South African Life Sciences curriculum, scientific investigations are viewed as a means to develop both scientific skills and Life Sciences concepts in students' quests to explain phenomena (DoE, 2003b). Indeed, one Expo student stated that scientific investigations enabled her develop new scientific skills and the scientific concept of blood pressure (p. 258). Development of concepts related to medical knowledge was also raised (p. 258). This study's contribution to the development of the skills and the concepts is consistent with So's (2003) observation that students learning science through scientific investigations concentrate on both scientific procedures and scientific concepts. Moreover, there were other aspects (in addition to skills and concepts) that the current Expo students reflected upon. This substantiated one Expo student's observation that scientific investigations actually cover different aspects of science (p. 258). Indeed, such investigations need commitment and proper organisation and management, both in their pursuit and in the conclusions drawn from them, with conventional values and attitudes the key elements in some cases (pp. 258-259). They develop one's ability to compile a scientific report and to investigate using the scientific method (p. 258). Nevertheless, the Expo students' conception of the scientific method suggests that they regarded it simply as a logical, orderly way in which to solve a problem or answer a question related to their respective investigations (Watson & James, 2004), without using process skills in the logical steps.

The descriptions of process skills in the South African Natural Sciences curriculum are framed around experiments or tests (DoE, 2002). The thrusts of the Assessment Standards stated under each Learning Outcome in DoE (2003b) are framed around tests and surveys. Hence, the current Expo projects were merely based on tests or surveys. However, the projects were innovative and were framed around critical research, random incidents in the students' families, or both, as well as interaction with peers at school. Thus, the Expo students exhibited a contexualised approach in their investigations. This is consistent with the findings in So (2003).

Apart from Expo students' ability to access relevant Life Science knowledge, they were expected to show understanding both of the application of the knowledge and of interpreting and making meaning of the knowledge. Specifically, they were expected to identify concepts, principles, laws, theories and models of Life Sciences in the context of eveyday life; and to describe and explain, and/or evaluate concepts, principles, laws, theories or models (DoE, 2003b).

The students were stimulated to pursue *background* knowledge to meet the needs inherent in their respective Expo projects, in their quest for more valued *practical* knowledge normally obtained in context (Tytler, 1992). So (2003) believed that these two emphasised sets of knowledge were fundamental in investigation projects because developing students' understanding of the relationship between empirical data and scientific theory constituted one of the aims of scientific investigations. However, So (2003) also observed and concluded that primary students' cognitive immaturity made it difficult for them to relate their findings to scientific theory. Was this the case with the current Expo students?

During the interviews, the Expo students were challenged when asked to account for how they interpreted information, and to provide descriptions and explanations of biological phenomena under investigation. However, evidence in their Expo reports showed that they were able to use relevant information, the data collected, and the resources they had to interpret and make sense of the information and data. The students' ability to access knowledge and relate their findings to scientific theories enabled them to subsequently provide meaningful scientific descriptions or explanations of health sciences concepts in their Expo reports, in their quest to construct new Life Sciences knowledge. Moreover, their proficiency in portraying the impact of phenomena investigated on the health or lifestyle of people at home or at school enabled them come up with suggestions and solutions to the challenges and problems investigated.

Recommendation

While it is apparent that learning through investigative projects not only provides students with opportunities to use scientific skills but also broadens their scope with respect to knowledge, it also requires a holistic approach, blended with "more inservice activities related to preparation for science fair competition" (Gifford & Wiygul, 1992, p. 118).

Furthermore, the current study showed not only a biased view in the South African science curricula with respect to scientific investigations but also the use of ambiguous terms in the descriptions of the prescribed process skills. For instance, the descriptions of the skills observing and comparing were framed around experiments or fair testing. In surveys or pattern seeking, the description based on experiments did not work, as students' proficiency in making observations and comparisons had to be focused on the descriptions of patterns and ordering and sequencing events (Devereux, 2000). On the other hand, the terms used by DoE (2002), such as "forms" in *recording information* and *communicating science information* and "items" in *sorting and classifying*, contributed in the current students' failure to understand the questions asked in relation to the three skills (e.g., Chapter 4, p. 186). Consequently, it is suggested that further research be made on the descriptions of process skills stipulated in the Natural Sciences curriculum in relation to various types of investigations. Such research may encompass use of alternative terms or phrases such as, for example, "ways" and "list of objects, subjects, information, and so on" in places of *forms* and *items*.

Research Question 3: How did articulation occur between the Expos, the science curriculum, and/or the science classroom practices?

The third question sought to provide evidence on whether there was tension or a harmonious interplay between the Expos, the science classroom practices, and/or the South African science curriculum.

Outcomes–based education (OBE) is the hallmark of the South African science curriculum, and its learner–centred and activity–based approach to education has proved invaluable in framing its principles (DoE, 2003b). Use of students' research projects has been recommended in such an approach to education (DoE, 2003d). It is believed (see DoE, 2003b) that use of the projects will enable ordinary students to meet the educational outcomes stipulated in the National Curriculum Statement (NCS) policy, including the ability to:

- Identify and solve problems and make decisions using critical and creative thinking;
- Collect, analyse, organise and critically evaluate information;
- Display and communicate their research; and
- Utilise science and technology effectively and critically, showing responsibility towards the environment and the health of others.

Hence, it is no surprise that Expo students studying Life Sciences are encouraged to conduct their Expo projects in accordance with OBE (*ESKOM Cape Town Expo for Young Scientists*, 2007) – to demonstrate their proficiency in understanding Life Sciences concepts and pertinent science processes. The results of the current study showed that Expo projects elicited inventive and innovative contributions from the students, as they showcased their problem–solving and creative skills at a higher level. As a result, they had the opportunity to develop critical thinking skills and other process skills essential to addressing the problems and challenges facing South Africa (DoE, 2003b). They were able to meet the above listed outcomes stipulated in NCS policy.

This study, therefore, explicitly supports the use of Expo projects as a mainstay of a harmonious interplay between ESKOM Expos and the South African Life Sciences curriculum.

Woolnough (1994) showed the importance of providing a good foundation for students' further education and career opportunities, and in particular the role played by the home. Expo students, by virtue of participating in the Expos, were propelled by experiences that encompassed support and encouragement, as well as high expectations from their homes and schools, to explore educational and potential career opportunities, such as medicine, that they could pursue at the tertiary level. In NCS policy, the Developmental Outcomes of the Life Sciences curriculum lay emphasis on students' "[exploration of] education and career opportunities" (DoE, 2003b, p. 2). Moreover, "educational and career links" (DoE, 2003b, p. 11) in NCS policy also include possible career pathways for school students in Higher Education such as, for instance, medicine and bioengineering. The common effort regarding provision of opportunities for students' exploration of educational and potential career opportunities further shows the interplay between the Expos and the NCS policy.

Woolnough (1994) also raised issues related to organisation and teaching that play a significant role in science learning by incorporating extra–curricular science activities and students' research projects. Findings from the current participating schools articulated his views on "dichotomy" in the context of extra–curricular science activities (Woolnough, 1994, p. 35). The students were able to use both their experiences at classroom level in the context of their investigations and the opportunity for personal challenge through Expo projects to shape their competence in developing scientific knowledge and techniques. Theoretical understanding and thinking, and the use of background knowledge and critical thinking during investigations to solve problems and challenges, were as important in the Expos as at classroom level. However, the results from Protea High School – considering the success of the school over the years – showed that the dichotomous approach might be more fruitful if it were blended with "high experimentation" in tandem with constructivist practices.

The South African Life Sciences curriculum also emphasises the exploration of indigenous knowledge systems related to science to expose students to different worldviews and allow them to appreciate, compare and evaluate scientific perspectives (DoE, 2003b). The current study's findings revealed that this learning outcome (Learning Outcome 3) was not common in the current Expo projects. For instance, in one leading project in the study, there was no information on the history of biometric systems or an extensive comparison of emerging biometric techniques. It is evident that this learning outcome remains a challenge not only at classroom level but also in Expos. Indeed, de Beer and Whitlock (2009) observed that indigenous knowledge is most often marginalised in the South African biology classrooms or is often very clinical when it is considered, albeit it could be incorporated in laboratory sessions and hands–on activities. Thus, it is not surprising that Expo students seemed to have considered pseudoscience as peripheral to issues that needed to be addressed during their scientific investigations.

Recommendation

Scientific investigations under the umbrella of Expos have a considerable potential to develop students' scientific skills and Life Sciences knowledge. They are a cornerstone in the interplay between the curriculum and the Expos. As a result, they are recommended in South African schools' science curricula. However, schools should anticipate challenges related to pedagogical issues, including those related to teachers' devotion to extra–curricular science activities (e.g., time and resources essential for research [Killen, 2010]). Woolnough (1994) suggested a solution to the challenges: "Judicious use of teachers, working within their own confidence and subject expertise, enables them to have the time and enthusiasm for extra–curricular [science] activities, and also teach science most effectively" (p. 24). Moreover, it is important that schools are knowledgeable of their students' characteristics, and have clear intentions. In relation to the intentions (see Killen, 2010), it is suggested that they should be based on whether a school:

- Wants students to achieve outcomes that are related to challenges and problems beyond the classroom.
- Wants to mould independent learners.
- Wants to tap into its students' curiosity.
- Has students that have considerable prior knowledge to guide their own learning, are self–motivated and can learn with minimal assistance.

Significance of the study

This study was completed at a time when an aspect of education that is of particular importance for South Africa's future was being examined, namely outcomes–based education (OBE). OBE poses challenges. The major challenge is rooted in the ongoing issues related to its implementation, which have led to calls for a major overhaul of educational policies (Chapter 1, pp. 12-13). This study has made a positive, fruitful, and practical contribution to improving at least one small aspect of the current science education system in South Africa. It provides an insight into the stakeholders (science curriculum developers, the schools, the science teachers, and ESKOM), the interplay between Expos and the South African science curriculum, and the associated development of students' skills within the context of an expanding framework of knowledge.

Most importantly, this study of Life Sciences in relation to factors which shape students' participation in Expos/Fairs, is unique in South Africa. Several comprehensive studies have been conducted on various science competitions for high–school students in different countries, including South Africa (e.g., Alant, 2006; Barak, 2004; Bunderson & Anderson, 1996; Rochford, 1998, 2007; Stewart, Qanya, & Rochford, 1999; Stazinski, 1988; Woolnough, 1994). However, no study on extra–curricular science activities, such as Science Fairs, Science Talent Quest/Search competitions or Science Expos has reported on school students' development of educational outcomes in tandem with their life histories. This study has therefore helped not only to fill a gap in the literature but also to make a positive and fruitful contribution to the field of science education. This contribution comprises evidence from case studies about the dynamics of the interactions between context, content, personal development and process skills engaged by high–school students participating in Expos.

Recommendations for further research

This study has offered insights regarding school students' development of process skills within the context of an expanding framework of knowledge. Recommendations for further research are discussed next in relation to studies which could emanate from the current research, and what needs to be done to optimise the development of process skills and scientific knowledge beyond classrooms.

The students who took part in the 2007 Expos were from English–speaking families in the Western Cape. The participating schools had sufficient resources and facilities for the students to succeed at the Expos. The study could be extended to the other provinces, especially those in which English is the second language and school resources and facilities are scarce. This practical approach may be essential for the production of more conclusive and generalisable results for students learning through ESKOM Expos.

Furthermore, this research has necessarily concentrated on a small multiple–case study in Life Sciences. The projects that were available were mainly focused on fair testing and pattern seeking kinds of investigation. This qualitative research approach has provided corroborative evidence regarding students learning through Expo projects that are presented in different categories of the Life Sciences (e.g., health care, animal sciences, plant sciences, medical sciences). Focus on studies that are framed around different approaches (i.e., quantitative paradigm, mixed method), and/or other types of investigation (e.g., classifying and identifying, exploring) may provide additional insights from different categories in Learning Areas such as, for instance, Physical Sciences and Engineering and Technology, as well as Life Sciences.

The overall results on the Expo students' life histories, which encompassed principles of interest, the origins of ideas for their projects, reasons for their participation and the role played by their homes and their schools, showed that there is an interplay between Expos and the National Curriculum Statement policy, which is perpetuated by one of the Life Sciences curriculum methodologies – investigative projects. The results also showed the relevance of the aforementioned components of the students' life histories in the development of scientific skills within the context of an expanding framework of knowledge, hence validating the significance of the students' experiences in schooling practices. These findings suggest an important aspect stated earlier (p. 263) – the need for inservice activities related to preparation for competitions which fall under the umbrella of Science Fairs. The findings tap into the imagination of teachers, as So (2003) puts it, in relation to "designing specific extended and holistic investigation activities in the teaching and learning of certain topics in the [science curricula]" (p. 198).

Concluding comments

There is growing evidence in the literature that curriculum reforms have embraced extra–curricular science activities (Chapter 2, p. 31). The current study was focused on these activities. It was framed around three questions.

Firstly, it sought to investigate factors that shaped the students' participation in the

Expos. The study showed the importance of students' life histories in their learning process. Indeed, Balas (1998) argued on the importance of a broader context of learning. The results of this study revealed a broader context in which students were able to venture beyond their classrooms to pursue issues of their interests and concerns, reflect and make sense of the associated educational experiences, recognise their sense of self–efficacy, and nurture confidence in their ability to achieve success.

Secondly, the study sought to investigate Expo students' skills and Life Sciences knowledge. It found that students' understanding, especially in regard to the scientific method, is as important as their ability in the "processes" of the skills they develop.

Thirdly, the study sought to investigate whether there is tension or a harmonious interplay between Expos, the science curriculum, and/or the science classroom practices. The study showed a harmonious interplay between Expos and the Life Sciences curriculum, exemplified by the students' research projects. Moreover, it showed that both Expos and Life Sciences encourage: (a) inventive and innovative contributions from the students, especially when they showcased their problem–solving and creative skills; and (b) exploration of educational and potential career opportunities. At the same time, the study showed that the exploration of indigenous knowledge systems related to science, in order to expose students to different worldviews and allow them to appreciate, compare and evaluate scientific perspectives (DoE, 2003b), remains a challenge in the science curriculum.

APPENDICES

APPENDIX A

Expo participants' consent form

CONSENT FORM

Researcher Name	: MOLEFE, 'Musetsi Leonard
Name of the University	: University of Cape Town – Humanities Graduate School, South Africa
Address	: 3 Kendal Court, Upper Liesbeek Road, 7700 Rosebank, CAPE TOWN
Phone	: 0739 8686 01
E-mail	: lenny2m@yahoo.co.uk

Thank you for agreeing to participate in this study.

This form outlines the purpose of the study and provides a description of your involvement and rights as a participant.

PURPOSE OF THE STUDY

The purpose of this research is to fulfill a course requirement of my doctoral degree in science education at the University of Cape Town, South Africa.

I would like to e*valuate* the viability of Expo investigative projects to reflect the attainment of Life Sciences–based scientific knowledge. Most importantly, I intend to study Expo students acquired, developed and demonstrated scientific skills at the same time. I would like to also uncover and explore how the Expo student's pertinent and significant life history as an aspirant young scientist may be reflected in his/her investigative project.

METHODS OF DATA COLLECTION

I plan to conduct audio– or video–recorded personal interviews, issue detailed coded questionnaires and use evidence in the Expo students' written projects reports. I intend to collect the data prior to the judging process in August 2007 in order to document the participants' own understanding and demonstration of the process skills contained in their experimental work.

You are encouraged to ask any questions at any time about the nature of the study and the methods that I am using. Your suggestions and concerns are important to me; please contact me at any time at the address/phone number listed above.

I'll use some of the information from this study to write my thesis. This thesis will be read by my supervisor, co–supervisor and external examiners and later lodged in the university library where it can be read.

I guarantee that the following conditions will be met:

1. Neither your name nor that of your school will be used at any point of information collection, or in the written report without consent.
2. If you grant permission for audio– or video–taping the interviews, no video–recorded tapes will be used for any purpose other than to do this study, and will not be played for any reason other than to do this study. At your discretion, these tapes will either be erased of destroyed.
3. Your participation in this research is voluntary; you have the right to withdraw at any point of the study, for any reason, and without any prejudice.

Do you grant permission to be interviewed?
YES_____NO_____

Do you grant permission to answer a questionnaire?
YES_____NO_____

I agree to the terms:

Respondent____Signature_____________________
Date________________

I agree to the terms that the above mentioned student participate in the study:

Parent/Guardian/Principal/Teacher__________________________________Signature_________________
Date________________

I agree to the terms:

Researcher: 'Musetsi Leonard Molefe

Signature___________________________________Date____________________

APPENDIX B

Sample of letters seeking permission from the mentors of Expo students to conduct interviews with them (mentors)

4 The Vines, 7 Alma Road
7700 Rosebank
CAPE TOWN
2008-08-18

Mr. S. Daniel*
CAPE TOWN

Dear Mr. Daniel

RE: Follow–up interview regarding the 2007 Protea* High School's Expo students' process skills and understanding of Life Sciences–based knowledge

The purpose of my doctoral study (at the University of Cape Town) is to analyse 2007 Expo students' scientific skills and understanding of Life Sciences–based knowledge embedded in their novel investigative projects. I also sought to understand, gain insights into and account for these students' personal, natural experiences and life histories in relation to their attainment of these educational outcomes (e.g., skills and knowledge) as the basis of a portrayal of how they learn through investigative projects.

I have studied your students' (Felicia, Gertrude, and Henry)* (i) acquired, developed and demonstrated scientific skills; (ii) their understanding of Life Sciences–based knowledge inherent to their projects; and (ii) uncovered and explored how their pertinent and significant life histories as aspirant young scientists might be reflected in their novel investigative projects. **Your assistance was very useful last year (2007) and I would appreciate your help once again.**

I wish to conduct a follow–up interview (of about 20minutes duration) with you regarding (i) the support you and the school provide to the Expo students and (ii) about your views concerning the Expo competitions. I plan to audio–record this interview with you.

I intend to conduct the interview with you in the second half of August 2008 at a place, date and time convenient to you.

You are encouraged to ask any questions at any time about the nature of the study and the data collection methods that I am using. As your suggestions and concerns are important to me; please contact me at any time at the address/phone number listed above.

I'll use some of the information from this study to write my thesis. This thesis will be read by my supervisor and external examiners and later lodged in the university library where it can be read.

I guarantee that the following conditions will be met:

1. Neither your name nor that of your school will be used at any point of information collection, or in the written report without consent.
2. If you grant permission for audio–taping the interviews, no tape will be used for any purpose other than to do this study. At your discretion, the tape will either be erased of destroyed.
3. Your participation in this research is voluntary; you have the right to withdraw at any point of the study, for any reason, and without any prejudice.

Please send me an e-mail regarding your decision to participate in this study. If you consent to the interview, I would bring a copy of this letter for your signature on the agreed date of the interview.

I look forward to your reply and hope that you will accede to my request.

Yours sincerely,

MOLEFE, 'Musetsi Leonard
Lenny2m@yahoo.co.uk
0739 8686 01

Do you grant permission to be interviewed (under the conditions stated in the above letter)?
YES_____NO_____

Expo students'
mentor/teacher___________________________________Signature____________________
Date____________

* The names of the participants, mentor and the school are pseudonyms.

APPENDIX C

Sample of letters seeking permission from schools principals to conduct the research with their Expo students

UNIVERSITY OF CAPE TOWN

School of Education
Graduate School in Humanities

Assoc. Professor K. Rochford

Room 5.14.2
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University Avenue
University of Cape Town
Rondebosch
7701

Phone: (021) 650 2777
(021) 650 2771
(021) 689 5459
Fax: (021) 650 3489
KR@humanities.uct.ac.za

TO WHOM IT MAY CONCERN: Mr Leonard Molefe

Mr Leonard Molefe is a qualified Biology teacher and a full-time doctoral research student in the Faculty of Humanities. He participated as an active member of the committee of the Expo for Young Scientists competition for schools held recently at the University of Cape Town. At the time of judging, and with the support of their biology teacher, one or more learners from your school kindly agreed to explain their projects in detail while being televised. For Mr Molefe, they focussed especially on the process skills they had used successfully during the development of their investigations.

Due to time constraints during the period of judging, Mr Molefe indicated that he would appreciate the opportunity to study in more detail selected learners' formal reports submitted with their biology Expo projects, with the permission of the learners and their teachers at different schools. His interest remains on the different types of science process skills that the learners used. After further analysis of their reports he would like to supply each Expo entrant with a summary of the many different ways in which Expo participants employed various types of process skills in their projects.

Would you be so kind as to arrange a meeting between the biology teacher at your school and Mr Molefe? He would hope to be able to discuss the possibility of studying in more detail some of the pages of the work submitted as part of the learners' biology projects for Expo. The names of your school, the biology teacher and the learners will be kept confidential.

As you know, the new Revised National Curriculum Statement (2002) and National Curriculum Statement (2003) place detailed emphasis on the successful learning of science process skills in science, and this is a valuable opportunity to study in detail how well enthusiastic young scientists are accomplishing these skills in schools like yours. We would appreciate very much any kind assistance that you are able to offer with this extended research with one or two of your learners who entered Expo 2006.

Yours faithfully,
K. Rochford
A/Professor K. Rochford

7 September 2006

OUR MISSION is to be an outstanding teaching and research university, educating for life and addressing the challenges facing our society.

APPENDIX D

Letter seeking permission from Western Cape Expo orgarnisers to conduct the research with the 2007 Expo students

University of Cape Town
Faculty of Humanities
School of Education
Private Bag
7700 RONDEBOSCH

18–07–2007

Diocesan College
Camp Ground Road
RONDEBOSCH
7700

Dear Mrs Olga Peel

RE: PERMISSION TO CONDUCT A RESEARCH WITH 2007 EXPO PARTICIPANTS

I am seeking permission to conduct research with the 2007 Expo participants in the Life Sciences categories.

The focus of my research is still on the *Expo participants'* process skills and learning outcomes. Consequently, I need access to the Cape Town and Stellenbosch Expos to conduct more research (which will include, among other things, some interviews and questionnaires) with the participants prior the judging process.

Where feasible, I intend to conduct the research with the students the day before their presentations (during the hours assigned for setting up their exhibitions).

I have included my published work on two of the 2005 Expo entrants in the *Technology* learning area, and I'm expecting feedback from another journal concerning my work (based on *Plant Sciences*) on one of the 2006 Cape Town Expo entrants.

I will, therefore, be grateful if my humble request would be considered.

Yours faithfully

'Musetsi Leonard Molefe

APPENDIX E

Semi–structured questionnaire

EXPO PARTICIPANT'S WRITTEN SELF–REPORT ON HIS/HER SUBMITTED PROJECT

CONGRATULATIONS OF YOUR DECISION TO ENTER THE 2007 ESKOM EXPO COMPETITION

You are invited to **complete** these details in your own handwriting in the spaces provided on the following pages, where they apply to your particular project.

YOUR NAME(S) :...

NAME OF YOUR SCHOOL/COLLEGE : ....

YOUR CATEGORY (e.g. Plant Sciences) :...

YOUR GENDER (e.g. Boy/Girl) :..

YOUR HOME LANGUAGE :...

1. Why did you enter the 2007 Expo competition?

2. What prompted/inspired you to start your project?

3. What made you think you could **do** this project?

4. How did you manage your project from start to finish bearing in mind the important **skills** you learnt during the entire process?

5. How did you decide on scientific items/objects you used in your investigation?

6. What presumptions did you make which led to your investigation?

   a) How the presumptions were met/not met?

   b) What more could you have done now that you have the project's outcomes?

7. What estimations did you make that were based on what you already knew?

8. What did your project tell you about science/scientific investigations?

*******************END*******************

THANK YOU FOR COMPLETING THESE DETAILS. WE WISH YOU ALL THE BEST

APPENDIX F

Semi–structured Interview questions for Expo students

2007 EXPO INTERVIEWS SCHEDULE

Part 1: Expo participant's life history/background

FOCUS	MAIN QUESTION	PROMPTS
Personal life and interests	1) Tell me a little bit about yourself. 2) What would you like to do when you finish school? 3) What is the role of science in your life?	
Family	4) Who are important people in your life? 5) What characteristics of them influenced you?	▪ What is your mother's occupation? ▪ What is her education? ▪ What is your father's occupation? ▪ What is his education?

Part 1 continued

FOCUS	MAIN QUESTION	PROMPTS
Expo and the role of science in the participant's life	6) How did you get to know about the Expo competition? 7) What made you decide about taking part in the Expo? 8) What have been the most important things you learnt in doing this project? 9) What have been the most important things you learnt about yourself from doing this project? 10) What do you think of your school life? 11) Tell me about learning science at school. 12) What is your favourite subject? 13) How do you feel about learning biology? 14) How do you go about learning biology?	▪ What are the most challenging things you encounter when learning science/biology at school? ▪ What are the important things you have learnt about science/biology at school?
Closure question	15) Is there anything that you want to tell me that I didn't mention during the interview?	

Part 2: Competence in Process Skills and Learning Outcomes

FOCUS	MAIN QUESTION	PROMPTS
Motivation and areas of interest	1) Tell me about your project. 2) Tell me more about the interest areas you explored in your project.	▪ How did you decide on what project to do? ▪ Who motivated you? ▪ What motivated you?
Process skills	3) What do you know about scientific processes that helped you in your project?	
	4) How did go about your observations? 5) What did you notice in your observations?	▪ Tell me about similarities and differences you noticed (e.g. in your data and items/objects you used). ▪ What were the most challenging things you encountered when carrying out your observations?
	6) Tell me more about your measurements. 7) How did you ensure that your measurements were accurate and precise?	
	8) How did you keep track of what was happening?	▪ Which forms of recording that information were easier to do? ▪ Which ones were challenging?
	9) How did you gather and manage scientific items/objects you used?	▪ What were the most challenging things you encountered as you named and grouped the scientific items/objects you used?

Part 2 continued

FOCUS	MAIN QUESTION	PROMPTS
Process skills	10) What information did you use for your project? 11) How did you get the information? 12) Tell me about how you made sense of the new information which you gathered from the experiments (Interpreting information).	▪ Tell me about what you noticed from the information. ▪ How did you arrange and analyse your data? ▪ How did the information help you to draw conclusions?
	13) What question(s) did you raise before you started your investigation?	▪ What prompted you? ▪ What did you do to ensure that the question(s) could be answered by scientific investigation? ▪ What more questions could you've asked now that you've the project's outcomes?
	14) Tell me about how you went about starting your project (Planning scientific investigation).	▪ What did you achieve that you intended for?
	15) What are many things you did as you carried out the practical part of your investigation (Conducting scientific investigation)?	▪ How did you go about fair testing?

Part 2 continued

FOCUS	MAIN QUESTION	PROMPTS
Process skills	16) Tell me more about how you decided on presenting your work to other people (e.g., other Expo participants and the public).	▪ Why did you use [form(s) of communicating science information used]? ▪ Which forms of presenting your work were simpler and easier to do? ▪ Which ones were more sophisticated and challenging?
General difficulties encountered	17) In general, what were the most difficult things you encountered when doing your project?	

APPENDIX G

A schedule of the semi–structured interviews of the Expo students' mentors

Mentors' interview questions

1. What do you think are the methods and practices of teaching you implement in Life Sciences that contribute to your Expo students' success at the Expos?

2. How do the methods and practices that you use in class hone their scientific skills and knowledge?

3. What support do you give to the Expo students when they plan, conduct and prepare their projects for the Expos?

4. What organisation structures concerning the Expos do you have in place here (name of the school) regarding Expo participation?

5. What strategies do this school implement to make Expo students' participation in the Expos a success?

6. What do you think is the role of Expo competitions in students' learning of Life Sciences?

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